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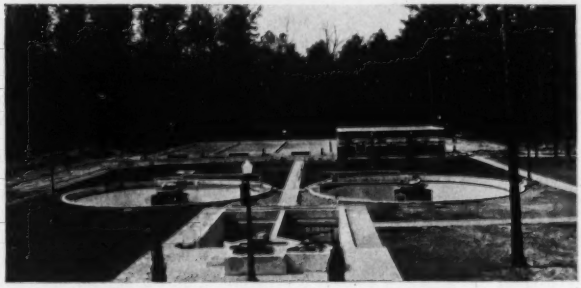

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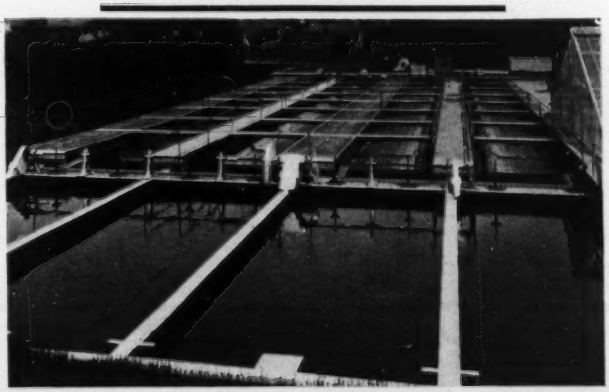

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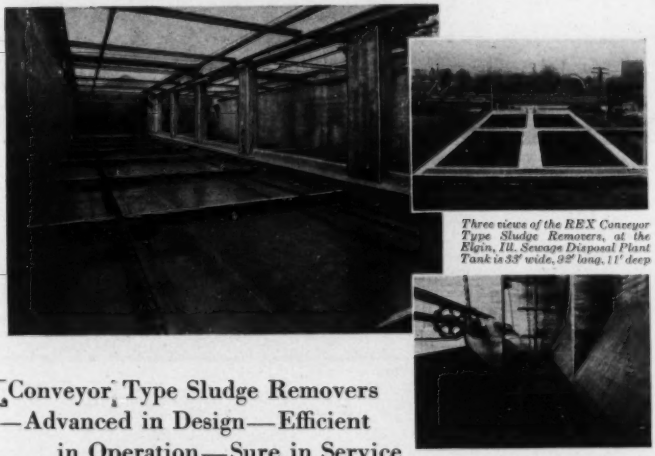

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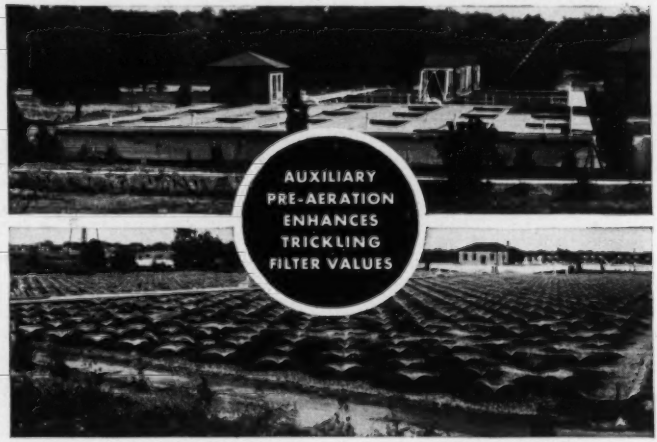

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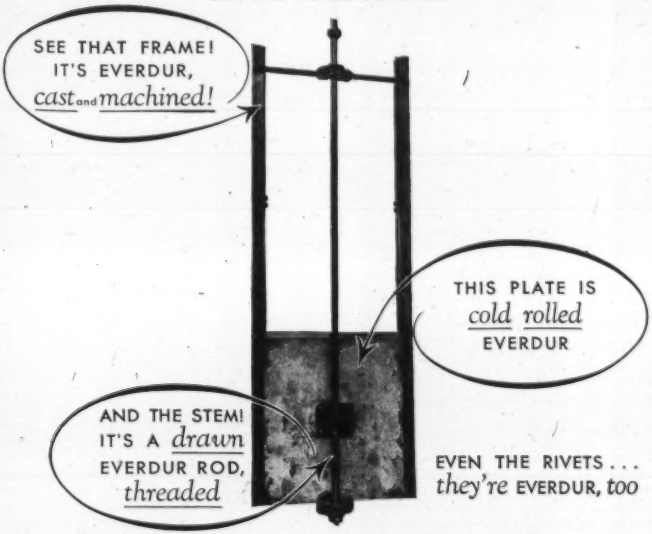
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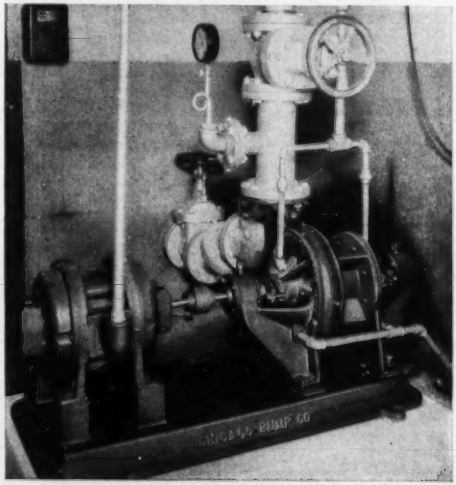

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Sewage Research

THE VACUUM FILTRATION OF ELUTRIATED SLUDGE *

By C. E. Keefer and Herman Kratz, Jr.

Principal Assistant Engineer and Junior Chemist, Bureau of Sewers, Baltimore, Md.

An extensive group of field experiments was begun August 29, 1933, and completed May 31, 1934, at the Baltimore sewage works. The results have indicated the possibility of reducing by more than 50 per cent the amount of ferric chloride needed to coagulate digested sewage sludge prior to filtration. Where ripe sludge is coagulated and filtered mechanically, the cost of the coagulant is a large part of the total expenditure. Any practicable means, therefore, of reducing the amount of chemicals used for coagulating purposes should result in a more general use of mechanical equipment for sludge dewatering.

These experiments were the continuation on a more extensive scale of an exhaustive group of laboratory investigations, made by A. L. Genter, consulting chemical engineer, at the Baltimore sewage works during the past few years. (See This Journal, **6**, 689, July, 1934.) His purpose has been to find means of reducing the amount of coagulant needed to flocculate sewage sludge. He has demonstrated that digested sludge contains considerable quantities of soluble ammonia derivative and ammonium compounds, which inhibit coagulation. By reducing the concentration of these compounds, he has shown that less chemicals are required to coagulate sludge.

The results obtained in the field have agreed closely with the laboratory work. The experiments have consisted of filtering sludges before and after soluble ammoniacal compounds have been partially removed. Moreover, the effect of these soluble putrefaction compounds at different concentrations on sludge filtration has been investigated. Similar but less extensive studies have been made when filtering raw and mixtures of raw and digested sludge. The comparative effectiveness of four different coagulants was observed. Of these most of the work was done with ferric chloride. Furthermore, cost estimates have been prepared on the filtration of the digested sludge at Baltimore, which amounts to approximately 60,000 lb. of dry solids daily. The cost of dewatering the sludge with vacuum filters, after a portion of the soluble putrefac-

* Presented before the Spring Meeting of the New York State Sewage Works Association, June 15, 1934.

tive compounds of nitrogen has been removed, is estimated to be $3.38 per ton of dry solids when using ferric chloride and $3.28 when using chlorinated copperas.

The Elutriation Process

Fresh sludge contains considerable decomposition products of protein as well as protein from food residues and bacteria. These products are broken down by bacteria into amides, amines, amino acids and finally into ammonium carbonate and bicarbonate. The amount of soluble amino acids and ammoniacal compounds has been designated by the concentration of nitrogen, which is called amino-ammonia nitrogen in this report. When fresh sludge is drawn from a preliminary settling tank, the amino-ammonia nitrogen usually varies from about 50 to 100 p.p.m. As the material putrefies, the concentration of these bases increases so that the amino-ammonia nitrogen will range from 700 to 1,000 p.p.m. when the solids are digested.

Genter has shown that the quantity of coagulant needed to flocculate sludge increased with higher concentrations of amino-ammonia nitrogen, and by removing a portion of these soluble compounds the amount of coagulant could be reduced. He demonstrated that this could be accomplished simply and comparatively inexpensively by elutriating or washing the decomposition products out of the sludge. The process consists of adding water to the sludge, mixing for a short period of time, allowing the solids to settle and decanting the supernatant. A portion of the ammoniacal compounds in the sludge diffuses in the water, and is removed. The larger the volume of water used, the greater is the amount of decomposition products extracted, and the smaller is the quantity of coagulant required. As amino acids and ammonium bicarbonate, which are found in considerable quantities in digested sludge, react chemically with ferric chloride, an excess of this coagulant must be used to satisfy this reaction as well as to discharge the negative potential of the colloids in the sludge.

Sludges Filtered

Most of the experiments were on the filtration of unelutriated and elutriated digested sludge. Some little work was done on the filtering of unelutriated and elutriated raw sludge, and on mixtures of raw and digested materials. The raw sludge was obtained from domestic sewage collected in a separate system of sewers with only small quantities of manufacturing wastes present. This sludge was removed from preliminary settling tanks, which had a detention period of about 2 hr., and were cleaned every 4 or 5 days. A portion of this sludge was pumped once a week into a digestion tank, where it remained for about 40 days

at a temperature of approximately 85° F. The unelutriated ripe material contained from 52.3 to 59.0 per cent volatile matter, and had a pH value varying from 6.8 to 7.3. Except when the sludge was purposely thickened or diluted, it contained from 5.7 to 8.1 per cent solids when unelutriated and from 5.2 to 7.9 per cent when elutriated. The unelutriated raw sludge contained from 73.5 to 77.4 per cent volatile matter, and 6.2 to 7.6 per cent solids with a pH value varying from 5.2 to 5.6.

Equipment Used

The equipment used during the experiments consisted of an Oliver vacuum filter, 3 ft. in diameter and 2 ft. face, with an effective filter area of 18.85 sq. ft., together with the necessary auxiliary machinery. The sludge to be dewatered was first discharged into three open storage tanks, one of which held 3,231 gal. and the other two 1,880 gal. each. Between these three tanks and the filter there were two steel tanks, provided with stirring equipment, where the coagulant was added. These two containers were at an intermediate elevation between the storage tanks and the filter so that the sludge flowed at all times by gravity. (See Diagram.)

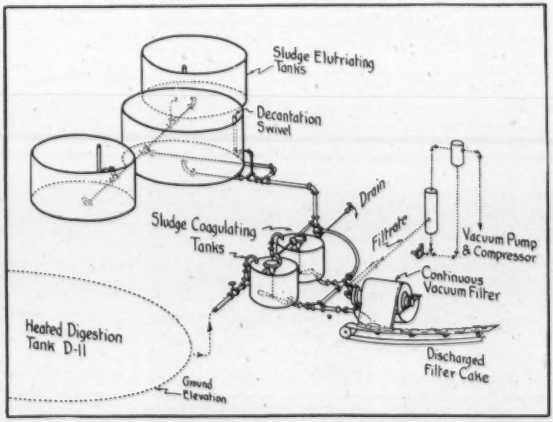


Diagram showing layout of plant for elutriation and filtration tests at Baltimore.

The general procedure was the same at all times. The sludge to be filtered was drawn into the storage tanks, where it was thoroughly mixed by aeration. A portion of the sludge, which amounted to about 1,100

lb., was then discharged into the coagulating tanks, the quantity being such that it usually remained in contact with the coagulant for less than 20 minutes. The longer this contact period, the less effective was the coagulant. After a 500-cc. sample of the sludge was obtained for analysis, the coagulant was added and mixed with the sludge for 1 to 5 minutes. Unelutriated sludge had to be mixed for a longer time than elutriated material. The coagulated sludge was then drawn to the filter, the speed of which was adjusted so that the cake had a dry exterior surface with a moisture of about 75 per cent. The cake from the above-mentioned 1,100-lb. batch was weighed on a platform scales, and sampled for moisture determination. The time of filtration was observed by means of a stop watch. Furthermore, samples of the filtrate were obtained at frequent intervals for analysis. By following this procedure it was possible to determine the amount of coagulant used per 100 lb. of dry solids filtered and the quantity of dry solids in the cake per square foot of filter area per hour. Successive 1,100-lb. batches of the same sludge were drawn into the coagulating tanks, each being flocculated with different quantities of chemical. The rate at which the sludge was filtered varied with the amount of coagulant used.

After these tests on the unelutriated sludge were completed, the remainder of the material in the storage tanks was elutriated by adding a known volume of water. The water and the sludge were thoroughly agitated manually and by means of an air jet for about 10 minutes, and the mixture was allowed to settle for 17 to 48 hours. The comparatively clear supernatant then contained a large portion of the soluble ammoniacal compounds, which had formerly been in the liquid surrounding and adsorbed by the sludge particles. This supernatant was drained off, and samples of it were collected every minute and composited for each run. Different quantities of coagulant were then added to each batch of elutriated sludge, and the mixture was agitated and filtered. The variation between the quantities of dry solids dewatered and the amounts of coagulant used when filtering the same sludge before and after elutriation has been shown by several groups of curves.

Results

The results of the experiments, which included 330 separate runs, have been summarized in two series. The first series, in which a large portion of the work was done, comprised the filtering of digested sludge. In the second series raw and mixtures of raw and digested sludge were filtered. The results obtained when dewatering digested material will be considered first.

One of the initial investigations was a study of the effect of the volume of elutriating water on the quantity of sludge filtered, when using

various amounts of coagulant. Unelutriated digested sludge, containing 6.0 per cent solids and from 710 to 770 p.p.m. (see Table I) of amino-ammonia nitrogen, was coagulated with ferric chloride, the dose varying from 6.1 to 12.2 lb. of anhydrous material per 100 lb. of dry solids in the sludge. The sludge was filtered with results (see Figure 1) that are generally to be expected when dewatering unelutriated digested material such as is obtained at Baltimore. A production of 7.8 lb. of dry solids per square foot of filter area per hour was obtained when using 6.1 lb. of anhydrous ferric chloride per 100 lb. of dry solids. When using 10.1 lb. of ferric chloride, the maximum production was 28.2 lb. of dry solids per hour.

A portion of the original sludge used in the above experiment was allowed to settle over night so that its solid content had increased from 6.0 to 6.5–6.7 per cent. The supernatant liquid was drawn off, and the sludge was filtered after adding different amounts of ferric chloride. When using less than 8 lb. of this coagulant per 100 lb. of dry solids, the thickened sludge gave the greater yield.

The investigation was then continued by elutriating the thickened sludge with an equal volume of water. The amino-ammonia nitrogen was reduced from 783 to 440 p.p.m. The sludge was then coagulated with ferric chloride and filtered. As indicated by Figure 1 the capacity was greatly increased as compared with the output when filtering unelutriated solids. For example, when dewatering thickened unelutriated sludge, which was coagulated with 6 lb. anhydrous ferric chloride per 100 lb. of dry solids, the filter capacity was about 10.2 lb. of dry solids per square foot of filter area per hour. When using this same amount of chemical to coagulate the elutriated sludge, the capacity was 26.6 lb. per hour, an output 2.6 times greater.

Portions of the original sludge were next elutriated with two or three volumes of water. By using two volumes of water, the amino-ammonia nitrogen in the sludge was reduced to an average of 294 p.p.m., and with three volumes of water the amino-ammonia nitrogen averaged 168 p.p.m. The use of more elutriating water resulted in greater cake productions with less coagulant. When three volumes of elutriating water to one volume of sludge were used, 4.0 lb. of anhydrous ferric chloride per 100 lb. of dry solids gave a production of 28.8 lb. of dry solids per square foot of filter area per hour. On the other hand, when this same sludge was filtered before elutriation, 4.7 lb. of ferric chloride yielded only 5.9 lb. of cake. In this particular instance the filter capacity was increased almost five-fold with a reduction of about 15 per cent in coagulant.

The elutriated sludge required much less coagulant than unelutriated material to produce the same filter output. When the capacity was 8

TABLE I.—*Effect of Elutriating Digested Sludge with Various Proportions of Water on Filter Capacity*
(Coagulant: $FeCl_3$. Tests made November 8–10, 1933)

Test No.	Duration of Test, Min.	Digested Sludge				Elutriate			Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent		Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Amino-Ammonia Nitrogen, P.P.M.	Suspended Solids, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Unelutriated															
1	5	6.0	56.8	710	7.0	—	—	—	12.2	27.3	74.3	—	—	25	16–18
2	5	6.0	56.8	710	7.0	—	—	—	10.1	28.2	74.7	—	—	25	16–17
3	6	6.0	59.0	730	7.0	—	—	—	8.1	20.0	74.3	—	—	40	14–16
4	18	6.0	59.0	730	7.0	—	—	—	6.1	7.8	74.1	63	—	113	18–19
5	5	6.0	55.7	770	7.0	—	—	—	9.1	25.0	75.4	43	6.0	25	16–18
6	5	6.0	55.7	770	7.0	—	—	—	11.2	27.3	76.4	—	5.5	25	15–19
Sludge Unelutriated but Thickened															
7	6	6.7	56.0	790	6.9	—	—	—	11.0	20.6	76.6	—	—	28	10–18
8	6	6.7	56.0	790	6.9	—	—	—	9.1	21.8	76.4	131	—	28	15–18
9	8	6.5	55.5	780	6.8	—	—	—	7.5	18.9	76.0	—	—	35	14–17
10	15	6.5	55.5	780	6.8	—	—	—	5.6	8.6	75.4	—	—	110	16–18
11	20	6.5	55.4	780	6.8	—	—	—	4.7	5.9	76.1	—	6.5	140	18–19
12	6	6.5	55.4	780	6.8	—	—	—	10.3	23.0	76.4	—	—	28	16–18

TABLE I.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge				Elutriate			Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent		Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Amino-Ammonia Nitrogen, P.P.M.	Suspended Solids, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Elutriated with 1 Volume of Water to 1 Volume of Sludge															
13	4	5.9	57.1	460	6.7	280	600	7.1	8.3	29.0	75.4	—	—	28	16–19
14	5	5.9	57.1	460	6.7	280	600	7.1	6.2	27.6	75.3	—	—	28	16–19
15	8	6.1	57.3	430	6.8	280	600	7.1	4.0	15.8	74.4	—	—	60	17–19
16	15	6.1	57.3	430	6.8	280	600	7.1	3.0	7.2	73.8	33	6.3	140	17–19
17	5	6.1	56.6	430	6.8	280	600	7.1	7.0	29.5	75.6	—	—	28	17–19
18	6	6.1	56.6	430	6.8	280	600	7.1	5.0	21.0	75.3	29	5.5	40	18–20
Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge															
19	5	6.0	56.2	290	6.7	240	230	7.1	6.1	25.1	75.2	—	—	30	17–19
20	5	6.0	56.2	290	6.7	240	230	7.1	4.1	26.0	75.1	—	—	30	16–18
21	15	6.1	56.4	300	6.7	240	230	7.1	2.0	6.9	73.8	79	6.5	116	16–18
22	9	6.1	56.4	300	6.7	240	230	7.1	3.0	14.8	73.7	—	—	60	16–18
23	5	5.9	56.9	290	6.7	240	230	7.1	5.1	26.2	75.3	61	5.5	30	16–19
Sludge Elutriated with 3 Volumes of Water to 1 Volume of Sludge															
24	5	6.0	56.1	170	6.4	170	184	7.1	4.0	28.8	74.9	61	5.3	30	16–19
25	5	6.0	56.1	170	6.4	170	184	7.1	3.0	25.3	75.2	—	—	30	17–19
26	10	6.2	56.2	170	6.4	170	184	7.1	2.0	13.8	73.6	—	—	58	17–20
27	6	6.2	56.2	170	6.4	170	184	7.1	4.9	22.9	75.2	—	—	30	17–19
28	20	6.3	56.0	160	6.4	170	184	7.1	1.5	5.7	74.3	42	6.2	146	17–19

lb. of dry solids per square foot of filter area per hour, the effect of elutriating the sludge with three volumes of water was to reduce the quantity of ferric chloride used from 5.4 to 1.6 lb. per 100 lb. of dry solids in the sludge filtered, a decrease of about 70 per cent. It is interesting to note that the amino-ammonia nitrogen in the sludge was reduced approximately 78 per cent by the elutriation process.

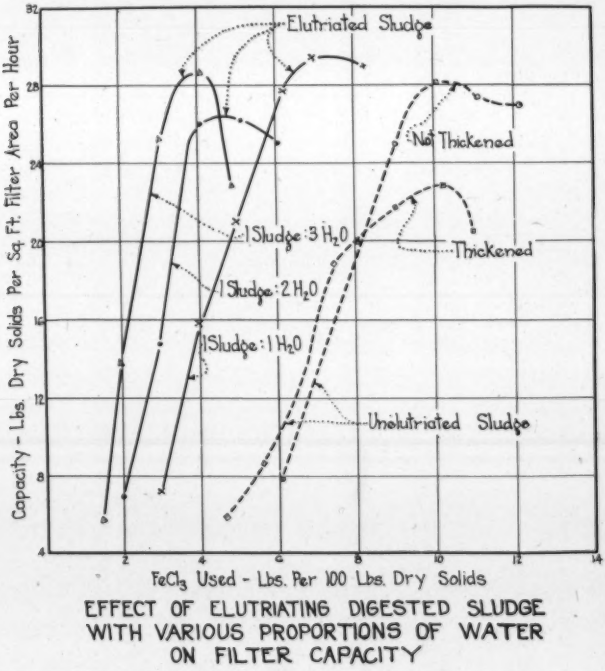
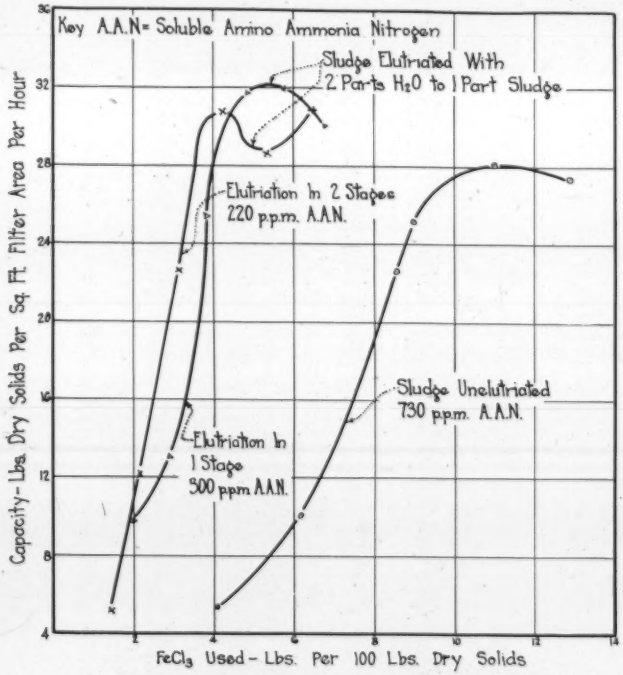

Elutriated Sludge
Not Thickened
1 Sludge : 3 H_2O
Thickened
1 Sludge : 2 H_2O
1 Sludge : 1 H_2O
Unelutriated Sludge
Capacity - Lbs. Dry Solids Per Sq. Ft. Filter Area Per Hour
$FeCl_3$ Used - Lbs. Per 100 Lbs. Dry Solids
EFFECT OF ELUTRIATING DIGESTED SLUDGE WITH VARIOUS PROPORTIONS OF WATER ON FILTER CAPACITY

FIG. 1.

Two-Stage Elutriation.—From a knowledge of the laws governing adsorption equilibrium it seemed reasonable to assume that the same volume of elutriate would wash out larger quantities of soluble ammoniacal products if the elutriating water were divided and mixed with the sludge in successive steps or stages and not all at one time. This hypothesis was verified in the following manner. Unelutriated digested

sludge, which contained about 734 p.p.m. of amino-ammonia nitrogen, was coagulated with different quantities of ferric chloride and filtered. A portion of the same sludge was then elutriated with two volumes of water, and the amino-ammonia nitrogen was reduced to an average of 302 p.p.m. The sludge was filtered with the results shown in Table II and Figure 2. Another portion of unelutriated sludge was mixed with



EFFECT OF ELUTRIATING DIGESTED SLUDGE IN 1 AND 2 STAGES ON FILTER CAPACITY

FIG. 2.

the same quantity of water, which was added in two stages. First, equal volumes of water and sludge were mixed; and after the sludge had settled, the supernatant was removed. The elutriation was then

TABLE II.—*Effect of Elutriating Digested Sludge in One and Two Stages on Filter Capacity*
(Coagulant: $FeCl_3$. Tests made October 31 to November 2, 1933)

Test No.	Duration of Test, Min.	Digested Sludge					Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Temperature, ° F.		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Unelutriated														
1	5	5.7	58.3	740	7.2	82	12.9	27.5	74.6	—	—	—	25	16–18
2	5	5.7	58.3	740	7.2	82	8.6	22.7	75.0	—	—	—	36	16–18
3	20	5.9	57.2	730	7.1	82	4.1	5.4	77.5	77	317	6.8	145	18–19
4	13	5.9	57.2	730	7.1	82	6.2	10.1	74.2	—	—	—	106	17–19
5	5	6.1	57.0	730	7.1	82	11.0	28.2	75.4	—	—	—	25	16–19
Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge in 1 Step (a)														
6	12	6.1	56.1	330	6.8	—	2.0	9.8	76.7	25	156	6.5	75	17–19
7	9	6.1	56.1	330	6.8	—	3.0	13.2	74.4	—	—	—	75	17–19
8	5	6.3	56.8	270	6.8	—	3.9	25.5	74.8	—	—	—	38	17–19
9	4	6.3	56.0	280	6.7	—	5.9	32.1	75.1	—	—	—	25	17–19
10	4	6.3	56.0	280	6.7	—	4.9	31.9	74.6	—	—	—	25	17–18
11	4	6.3	55.6	320	6.7	—	6.8	30.1	74.4	—	—	—	25	17–19

(a) Elutriate contained 150 p.p.m. amino-ammonia nitrogen, 217 p.p.m. B.O.D. (5 days at 20° C.), 400 p.p.m. suspended solids and had a pH value of 7.1.

TABLE II.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge					Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Temperature, ° F.		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge in 2 Steps (b)														
12	4	5.7	55.4	220	6.6	63	6.5	30.9	73.9	—	—	—	25	16–19
13	5	5.7	55.4	220	6.6	63	5.4	28.7	73.1	—	—	—	25	16–19
14	4	5.7	55.5	220	6.5	63	4.3	31.0	73.7	—	—	—	25	16–19
15	5	5.7	55.5	220	6.5	63	3.2	22.7	74.3	—	—	—	36	18–19
16	9	5.6	54.7	210	6.5	63	2.2	12.3	74.2	94	44	5.9	75	17–19
17	20	5.6	54.7	210	6.5	63	1.5	5.2	74.7	—	—	—	140	18–19

(b) Elutriate from 1st step contained 220 p.p.m. amino-ammonia nitrogen, 582 p.p.m. B.O.D. (5 days at 20° C.), 922 p.p.m. suspended solids and 7.1 pH value. Elutriate from 2nd step contained 150 p.p.m. amino-ammonia nitrogen, 107 p.p.m. B.O.D. (5 days at 20° C.), 382 p.p.m. suspended solids and had a pH value of 6.9.

TABLE III.—*Effect of Reducing Amino-Ammonia Nitrogen in Digested Sludge on Filter Capacity. Series No. 1.*
(Coagulant: $FeCl_3$. Tests made January 8–12, 1934)

Test No.	Duration of Test, Min.	Digested Sludge					Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Temperature, ° F.		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Unelutriated														
1	4	6.5	57.3	880	—	88	12.6	26.8	75.6	108	—	—	25	15–18
2	10	6.5	57.3	880	—	88	10.5	11.9	76.0	61	296	6.1	103	17–18
3	6	6.5	58.0	880	—	88	14.8	24.7	74.5	148	210	—	35	18–19
4	5	6.5	58.0	880	—	88	13.7	30.3	76.4	151	182	—	25	17–18
5	6	6.4	57.5	880	—	88	11.8	23.5	75.2	111	159	4.9	35	18–19
6	10	6.4	57.5	880	—	88	9.7	8.0	73.7	56	136	—	148	17–18
Sludge Elutriated (a) Amino-Ammonia Nitrogen Content: 710 P.P.M.														
7	5	6.2	56.6	710	7.0	64	13.1	24.1	76.3	117	—	—	29	16–19
8	6	6.2	56.6	710	7.0	64	11.0	20.8	76.7	96	—	—	36	17–18
9	9	6.1	56.9	710	7.0	64	9.0	13.7	74.6	66	—	—	62	15–19
10	6	6.1	56.9	710	7.0	64	12.4	23.2	77.0	126	—	—	26	15–18
11	10	5.7	57.5	710	7.0	64	7.2	7.6	75.5	44	—	—	130	18–19

(a) Volume of elutriating water not determined.

TABLE III.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge					Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Temperature, ° F.		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Amino-Ammonia Nitrogen Content: 680 P.P.M.														
12	5	6.1	56.5	680	7.2	63	11.2	23.4	77.1	116	151	—	26	16–19
13	8	6.1	56.5	680	7.2	63	8.9	16.7	76.5	75	112	5.5	45	15–19
14	6	6.0	56.7	680	7.2	63	12.6	23.4	76.1	136	188	—	26	16–19
15	10	6.0	56.7	680	7.2	63	6.8	8.7	74.7	46	80	6.0	108	16–19
16	10	5.7	57.3	680	7.2	63	6.0	6.3	75.9	34	82	6.3	145	18–19
Amino-Ammonia Nitrogen Content: 670 P.P.M.														
17	5	6.3	56.4	670	6.9	54	10.8	23.9	77.0	123	252	4.9	28	17–19
18	8	6.3	56.4	670	6.9	54	8.7	18.0	76.6	70	115	5.5	42	17–19
19	10	6.4	56.2	670	7.0	54	6.4	10.7	75.6	45	87	6.0	78	17–19
20	10	6.4	56.2	670	7.0	54	4.3	5.4	76.8	38	144	6.4	153	17–19
21	6	6.2	56.2	670	7.1	54	9.8	22.7	77.5	93	123	5.4	26	18–19
Amino-Ammonia Nitrogen Content: 450 P.P.M.														
22	6	5.7	56.6	450	6.9	54	9.5	22.5	76.7	95	124	5.0	26	18–19
23	6	5.7	56.6	450	6.9	54	7.1	20.1	76.4	62	107	5.4	38	18–19
24	9	5.6	55.6	450	6.9	54	4.9	10.5	75.6	87	69	6.1	63	18–19
25	10	5.6	55.6	450	6.9	54	2.4	4.1	76.6	30	110	6.7	153	17–18
26	5	5.2	55.9	450	7.0	54	9.2	20.7	76.5	89	72	5.2	26	18–19

TABLE III.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge					Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Temperature, ° F.		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum In.,
Amino-Ammonia Nitrogen Content: 370 P.P.M.														
27	6	5.6	56.6	370	6.9	—	7.4	20.3	76.7	22	92	5.3	26	18–19
28	9	5.6	56.6	370	6.9	—	4.9	13.8	76.6	35	71	6.0	51	18–19
29	10	5.4	56.9	370	7.0	—	2.5	4.2	74.9	65	75	6.7	153	17–19
30	6	5.4	56.9	370	7.0	—	8.8	21.6	77.0	32	81	5.2	26	16–19
31	6	5.2	56.7	370	6.9	—	10.5	17.4	76.3	—	—	—	26	18–19
Amino-Ammonia Nitrogen Content: 180 P.P.M.														
32	5	6.3	55.4	180	6.5	43	4.3	23.0	75.9	—	—	—	28	18–19
33	10	6.3	55.4	180	6.5	43	2.2	9.4	75.4	—	—	—	87	18–19
34	5	6.2	56.0	180	6.5	43	5.5	22.9	76.2	93	76	5.3	27	18–19
35	10	6.2	56.0	180	6.5	43	1.7	5.2	75.4	25	32	6.2	148	17–18
36	5	6.2	55.9	180	6.4	43	6.7	23.7	76.9	—	—	—	27	18–19
37	6	6.2	55.9	180	6.4	43	7.8	21.5	76.5	—	—	—	27	18–19

repeated with a fresh supply of water. By this two-stage elutriation the amino-ammonia nitrogen in the sludge was reduced to 217 p.p.m., with the result that somewhat less ferric chloride was required.

Effect of Ammoniacal Products on Filtration.—The next step in the investigation consisted in determining to what extent the quantity of sludge dewatered was affected by the concentration of soluble am-

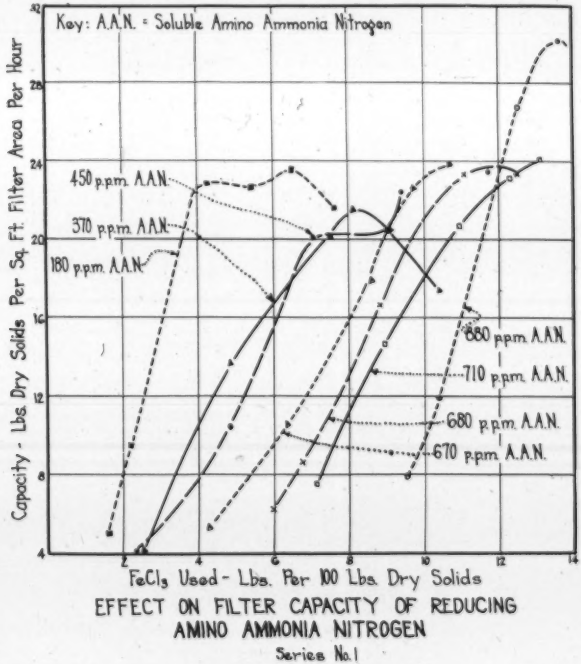

Key: A.A.N. = Soluble Amino Ammonia Nitrogen
Capacity - Lbs. Dry Solids Per Sq. Ft. Filter Area Per Hour
450 p.p.m. A.A.N.
370 p.p.m. A.A.N.
180 p.p.m. A.A.N.
880 p.p.m. A.A.N.
710 p.p.m. A.A.N.
680 p.p.m. A.A.N.
670 p.p.m. A.A.N.
FeCl3 Used - Lbs. Per 100 Lbs. Dry Solids
EFFECT ON FILTER CAPACITY OF REDUCING AMINO AMMONIA NITROGEN
Series No. 1

FIG. 3.

moniacal products present. As in the previous experiments unelutriated sludge was dewatered first. Portions of this same material were then elutriated with various quantities of water so that different amounts of the ammoniacal products remained in the sludge. Two groups of tests were made. In the first group the unelutriated sludge had an amino-ammonia nitrogen content of 880 p.p.m. (see Table III and Figure 3).

TABLE IV.—*Effect of Reducing Amino-Ammonia Nitrogen in Digested Sludge on Filter Capacity. Series No. 2*
(Coagulant: $FeCl_3$. Tests made January 15–23, 1934)

Test No.	Duration of Test, Min.	Digested Sludge					Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Temperature, ° F.		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Unelutriated														
1	3	6.1	55.9	800	7.0	83	13.5	23.7	74.6	—	—	—	26	17–19
2	6	6.1	55.9	800	7.0	83	11.2	20.5	75.4	94	104	5.0	37	17–19
3	8	5.9	55.4	800	7.0	83	9.3	13.6	74.3	—	—	—	64	16–19
4	10	5.9	55.4	800	7.0	83	7.0	7.5	75.0	59	40	6.1	143	18–20
5	5	5.7	55.1	800	7.0	83	13.1	22.4	75.9	—	—	—	27	18–19
6	10	5.7	55.1	800	7.0	83	6.0	5.6	75.3	—	—	—	167	17–19
Sludge Elutriated (a) Amino-Ammonia Nitrogen Content: 700 P.P.M.														
7	5	6.5	55.0	700	7.1	63	10.6	24.9	76.3	112	222	4.9	28	18–19
8	7	6.5	55.0	700	7.1	63	8.5	18.2	76.2	—	—	—	44	18–19
9	10	6.6	55.2	700	7.1	63	6.2	10.1	75.4	—	—	—	103	18–19
10	10	6.6	55.2	700	7.1	63	4.2	6.2	75.7	49	122	6.4	146	18–19
11	6	6.5	55.2	700	7.1	63	12.6	22.5	76.7	—	—	—	28	17–18

(a) Volume of elutriating water not determined.

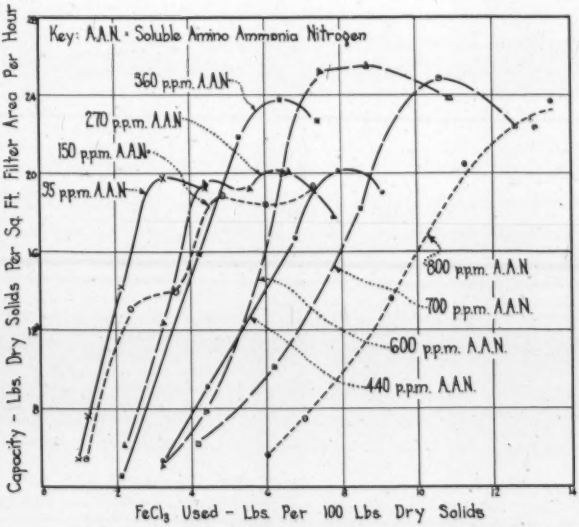
TABLE IV.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge					Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Temperature, ° F.		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Amino-Ammonia Nitrogen Content: 600 P.P.M.														
12	6	6.3	54.6	600	7.0	63	10.8	23.9	76.4	—	—	—	28	18–19
13	6	6.3	54.6	600	7.0	63	8.7	25.5	76.5	91	161	4.7	28	19–20
14	7	6.3	54.9	600	7.0	63	6.5	20.0	76.6	—	—	—	36	18–19
15	10	6.3	54.9	600	7.0	63	4.4	7.9	75.7	—	—	—	104	19–20
16	6	6.3	55.1	600	7.0	63	7.5	25.3	77.3	—	—	—	28	18–19
17	8	6.3	55.1	600	7.0	63	3.2	5.1	75.1	23	89	6.5	146	18–19
Amino-Ammonia Nitrogen Content: 440 P.P.M.														
18	6	6.0	55.0	440	7.1	41	9.1	19.0	75.8	103	220	4.1	30	18–19
19	9	6.0	55.0	440	7.1	41	6.8	16.7	75.4	—	—	—	42	18–19
20	10	6.0	55.1	440	7.1	41	4.5	9.1	74.4	—	—	—	89	18–19
21	6	6.0	55.1	440	7.1	41	7.9	20.2	77.2	—	—	—	30	18–19
22	6	6.0	55.1	440	7.1	41	3.2	5.0	74.5	28	75	6.2	144	18–19
Amino-Ammonia Nitrogen Content: 360 P.P.M.														
23	5	6.4	55.4	360	6.9	47	6.4	23.8	76.0	—	—	—	28	18–19
24	10	6.4	55.4	360	6.9	47	4.3	15.9	75.7	—	—	—	42	18–19
25	8	6.5	55.4	360	6.9	47	2.1	4.5	75.0	29	126	6.5	146	17–19
26	7	6.5	55.4	360	6.9	47	5.3	21.8	76.7	51	98	5.9	28	18–19
27	6	6.5	54.7	360	6.9	47	7.4	22.7	76.5	92	116	5.1	28	18–19

TABLE IV.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge					Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Temperature, ° F.		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Amino-Ammonia Nitrogen Content: 270 P.P.M.														
28	6	6.2	54.0	270	7.1	41	6.6	20.1	76.3	90	100	4.9	28	19–20
29	7	6.2	54.0	270	7.1	41	4.4	19.6	76.3	—	—	—	28	18–19
30	7	6.1	55.3	270	7.1	41	5.6	19.2	76.4	72	102	5.1	28	18–19
31	7	6.1	55.3	270	7.1	41	7.8	17.8	76.3	—	—	—	28	18–19
32	11	6.2	54.5	270	6.9	41	3.3	12.4	74.6	—	—	—	58	18–19
33	6	6.2	54.5	270	6.9	41	2.2	6.2	72.9	34	19	6.0	144	18–19
Amino-Ammonia Nitrogen Content: 150 P.P.M.														
34	6	5.6	55.5	150	6.5	43	7.3	19.3	74.8	—	—	—	26	18–19
35	6	5.6	55.5	150	6.5	43	4.9	18.9	75.2	108	116	4.7	26	18–19
36	9	5.7	55.2	150	6.5	43	2.4	13.0	75.3	—	—	—	44	18–19
37	7	5.7	55.2	150	6.5	43	6.0	18.4	76.1	135	69	3.5	26	18–19
38	10	5.7	55.0	150	6.5	43	1.2	5.5	75.6	37	38	5.8	125	18–19
39	8	5.7	55.0	150	6.5	43	3.6	15.0	76.1	—	—	—	34	18–19
Amino-Ammonia Nitrogen Content: 95 P.P.M.														
40	6	6.2	54.1	95	6.6	42	4.4	19.2	74.1	68	190	5.0	31	18–19
41	6	6.2	54.1	95	6.6	42	3.3	19.8	74.8	—	—	—	29	18–19
42	9	6.6	55.6	95	6.6	42	2.1	14.2	74.2	—	—	—	38	18–19
43	10	6.6	55.6	95	6.6	42	1.5	7.8	73.4	—	—	—	82	19–20
44	11	6.4	54.1	95	6.6	42	1.0	5.4	72.8	33	32	5.8	117	18–19

By successive elutriations the amino-ammonia nitrogen was reduced to 710, 680, 670, 450, 370 and 180 p.p.m. As shown in Figure 3, greater cake outputs were obtained, and less coagulant was required where large quantities of compounds containing amino-ammonia nitrogen were removed. For example, when the production of cake from the elutriated sludge with an amino-ammonia nitrogen content of 180 p.p.m. is compared with the unelutriated material containing 880 p.p.m. of amino-ammonia nitrogen, 2 lb. of ferric chloride per 100 lb. of dry solids were required to yield 8 lb. of dry cake per square foot of filter area per hour from the elutriated sludge and 9.7 lb. of ferric chloride to give the same production from the unelutriated material. In this case there was a reduction in coagulant used of 80 per cent with a corresponding decrease in amino-ammonia nitrogen in the sludge of 80 per cent.


Key: A.A.N. - Soluble Amino Ammonia Nitrogen
360 p.p.m. A.A.N.
270 p.p.m. A.A.N.
150 p.p.m. A.A.N.
35 p.p.m. A.A.N.
800 p.p.m. A.A.N.
700 p.p.m. A.A.N.
600 p.p.m. A.A.N.
440 p.p.m. A.A.N.
Capacity - Lbs. Dry Solids Per Sq. Ft. Filter Area Per Hour
FeCl3 Used - Lbs. Per 100 Lbs. Dry Solids
EFFECT ON FILTER CAPACITY ON REDUCING AMINO AMMONIA NITROGEN
Series No 2
FIG. 4.

The results of a duplicate group of experiments are given in Table IV and Figure 4. The unelutriated sludge in this instance had a

TABLE V.—*Effect of Solid Content in Unelutriated and Elutriated Sludge on Filter Capacity. Series No. 1*

(Coagulant: $FeCl_3$. Tests made April 2–6, 1934)

Test No.	Duration of Test, Min.	Digested Sludge				Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
						Sludge Unelutriated							
						Solid Content: 4.0 to 4.1%							
1	9	4.1	54.6	900	7.2	11.7	9.0	76.0	31	92	—	67	18–20
2	6	4.1	54.6	900	7.2	14.6	14.5	75.8	—	—	—	40	18–20
3	6	4.0	54.4	900	7.2	18.2	14.2	75.0	—	—	—	37	18–19
4	6	4.0	54.4	900	7.2	16.7	14.2	75.7	—	—	—	37	18–19
5	5	4.0	53.7	910	7.2	4.6	3.4	76.5	28	90	—	142	18–20
						Solid Content: 5.5 to 5.7%							
6	12	5.7	54.1	910	7.2	8.5	8.2	76.6	—	—	—	92	18–19
7	6	5.7	54.1	910	7.2	10.6	20.7	77.0	—	—	—	28	18–19
8	5	5.5	53.8	870	7.2	13.2	24.3	76.4	76	97	5.5	28	18–19
9	5	5.5	53.8	870	7.2	15.4	23.3	76.2	—	—	—	28	18–19
10	10	5.5	54.7	890	7.2	6.6	6.7	77.9	30	185	—	142	18–20

TABLE V.—*Continued*

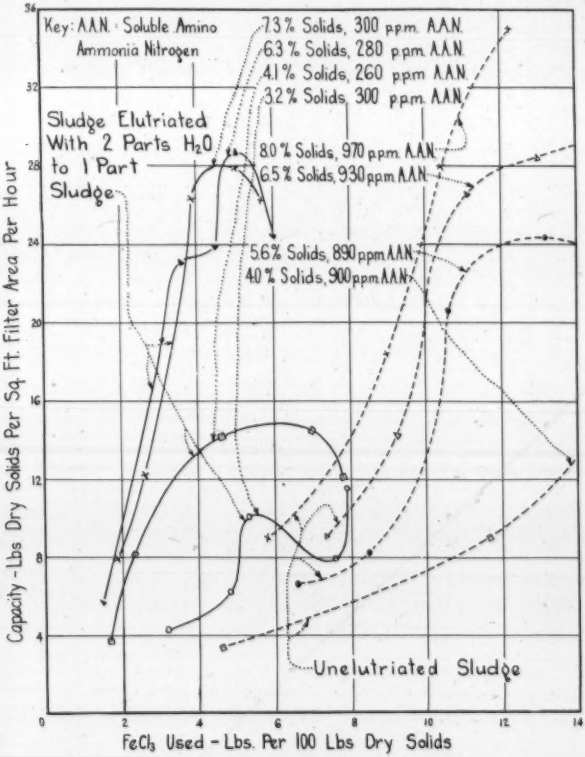
Test No.	Duration of Test, Min.	Digested Sludge				Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Solid Content: 6.5 to 6.6%													
11	10	6.5	54.2	940	7.2	7.4	9.0	77.6	46	154	6.1	123	18–19
12	5	6.5	54.2	940	7.2	11.1	26.5	76.3	109	110	6.0	32	18
13	5	6.5	54.6	900	7.1	13.0	28.4	76.0	—	—	—	32	16–18
14	9	6.5	54.6	900	7.1	9.3	14.3	76.8	—	—	—	79	18
15	5	6.6	54.7	940	7.2	14.6	29.3	76.0	—	—	—	32	18–19
Solid Content: 7.9 to 8.1%													
16	5	7.9	54.1	980	7.2	12.3	35.0	77.4	191	217	5.0	27	18–19
17	9	8.0	54.1	950	7.2	9.0	18.4	76.7	—	—	—	72	15–17
18	7	8.0	54.1	950	7.2	10.5	27.9	77.3	—	—	—	27	15–16
19	10	8.1	53.9	970	7.2	5.8	9.0	76.1	53	72	5.7	143	15–18
Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge													
Solid Content: 2.9 to 3.5%													
20	6	3.5	55.3	330	7.2	7.9	11.6	73.1	—	—	—	47	18–19
21	7	3.5	55.3	330	7.2	5.3	10.1	72.5	43	68	—	56	18–20
22	10	2.9	55.7	280	7.2	3.2	4.3	72.2	14	28	—	120	18–20
23	10	2.9	55.7	280	7.2	4.8	6.2	71.4	—	—	—	81	18–20
24	8	3.0	54.4	280	7.2	7.6	7.3	72.5	—	—	—	56	17–19

TABLE V.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge				Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P_1 P.M.	Suspended Solids, P_1P_2M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Solid Content: 4.0 to 4.2%													
25	5	4.0	54.8	260	6.9	7.0	14.5	73.8	92	127	3.9	32	18–20
26	5	4.0	54.8	260	6.9	4.7	14.2	73.8	—	—	—	32	18–20
27	9	4.1	54.3	260	6.9	2.3	8.2	74.9	17	50	6.3	56	18–20
28	12	4.1	54.3	260	6.9	1.7	3.7	75.8	—	—	—	126	18–19
29	7	4.2	54.3	270	6.9	7.8	12.1	74.7	—	—	—	38	19–20
Solid Content: 6.2 to 6.5%													
30	5	6.3	54.5	280	7.1	4.5	23.9	76.5	87	74	5.3	31	20
31	7	6.3	54.5	280	7.1	3.0	19.1	76.7	—	—	—	38	19–20
32	10	6.2	53.6	290	7.0	1.5	5.7	76.9	27	53	5.9	154	19–20
33	5	6.2	53.6	290	7.0	6.0	24.4	77.9	—	—	—	24	19
34	5	6.5	53.7	280	7.0	5.0	28.8	77.9	—	—	—	24	19
35	6	6.5	53.7	280	7.0	3.6	23.2	77.7	—	—	—	32	19
Solid Content: 7.1 to 7.4%													
36	5	7.1	53.1	300	7.2	3.9	26.3	76.6	77	135	5.4	28	19
37	12	7.1	53.1	300	7.2	2.6	12.2	76.2	52	46	5.8	82	19
38	5	7.4	53.3	300	7.1	5.1	28.0	76.7	—	—	—	28	19–20
39	6	7.4	53.3	300	7.1	5.7	26.2	77.3	—	—	—	28	19–20
40	10	7.3	52.9	290	7.1	1.9	8.0	75.2	—	—	—	132	19

Note: Chemical characteristics of elutriate not determined.

slightly lower amino-ammonia nitrogen content of 800 p.p.m. After several elutriations the amino-ammonia nitrogen was reduced to 95 p.p.m. This sludge yielded 5.4 lb. of dry cake per square foot of filter area per hour with the remarkable low dosage of 1.0 lb. of ferric chloride per 100 lb. of dry solids. In these two groups of experiments no attempt was made to determine the volume of elutriating water.



EFFECT OF PER CENT SOLIDS IN SLUDGE ON FILTER CAPACITY

Series No. 1

FIG. 5.

Effect of Solid Content in Sludge on Filtration.—As it was possible to determine the filter capacity when dewatering the same sludge by varying one or more of the physical or chemical characteristics of the material, the effect of the solid content of the sludge on the amount that could be dewatered was investigated. Two series of tests were made. The results of the first series are given in Table V and Figure 5.

Digested sludge, containing 8.0 per cent solids, was put into the three elutriating tanks. A portion of this material was filtered with the results as shown. Sufficient supernatant liquor from a digestion tank was then added to reduce the solid content to 6.5 per cent. Further additions of sludge liquor reduced the solid content to 5.6 and 4.0 per cent. Each time the diluted sludge was filtered, and the cake output was determined when using different quantities of ferric chloride.

A portion of the original sludge was then elutriated with two parts of water to one part of sludge in two stages or steps. This material was also filtered, both in its concentrated form with 7.3 per cent solids, and also after it had been diluted to contain 6.3, 4.1 and 3.2 per cent solids. As indicated by Figure 5, the solid content of the sludge had a marked influence on the filter capacities. For instance, when using 8.0 lb. of ferric chloride per 100 lb. of dry solids, the filtering of the unelutriated sludge, containing 4.0 per cent solids, resulted in an output of 5.7 lb. of dry solids per square foot of filter area per hour, whereas the same material with 8.0 per cent solids gave a yield of 14.3 lb. of cake, a production 2.5 times greater.

The amount of moisture in the unelutriated sludge had a much greater influence on the quantity of coagulant used than was the case with elutriated material. This condition was undoubtedly due to the presence of more soluble ammoniacal compounds in the liquor of unelutriated sludge. The maximum filtration rates when dewatering unelutriated solids not only materially decreased with lower solid concentrations, but this decrease was accompanied by a decided increase in the amount of coagulant necessary to produce these maximum rates. However, the quantities of ferric chloride required to produce maximum rates of filtration, when dewatering elutriated sludge, are practically identical for sludges containing different amounts of solids. These maximum rates decrease with lower concentrations of solids because of the greater quantity of filtrate that has to be sucked through a unit area and thickness of cake in a given time. The results of the second series of tests are given in Table VI and Figure 6.

Coagulating with Various Chemicals.—Two groups of experiments were made to study the filter capacities when the unelutriated and elutriated sludges were treated with different coagulants. The coagulants used were ferric chloride, chlorinated copperas, ferric sulphate (Fer-

TABLE VI.—*Effect of Solid Content in Unelutriated and Elutriated Sludge on Filter Capacity. Series No. 2*
(Coagulant: $FeCl_3$. Tests made December 11–22, 1933)

Test No.	Duration of Test, Min.	Digested Sludge					Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Temperature, ° F.		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Unelutriated														
Solid Content: 3.7 to 4.2%														
1	15	4.2	52.7	650	7.1	41	7.8	5.1	76.0	33	93	6.3	93	18–20
2	15	4.2	52.7	650	7.1	41	9.8	5.7	75.8	46	58	6.0	93	17–19
3	15	3.7	54.9	660	7.2	41	13.1	6.9	76.4	49	59	5.3	72	18–19
4	15	3.7	54.9	660	7.2	41	17.5	6.2	74.0	—	—	—	93	18–19
5	15	4.2	55.4	670	7.2	41	13.5	8.0	75.4	—	—	—	66	17–19
Solid Content: 5.1 to 5.3%														
6	6	5.3	54.8	780	6.9	47	9.2	16.9	77.4	75	157	5.5	34	18–19
7	11	5.3	54.8	780	6.9	47	6.9	9.8	76.7	—	—	—	58	17–18
8	20	5.2	54.3	800	6.9	47	4.7	3.7	76.3	29	98	6.4	151	17–18
9	9	5.2	54.3	800	6.9	47	11.7	11.2	76.7	104	274	4.5	48	17–18
10	8	5.1	54.9	800	6.9	47	10.7	14.2	77.5	—	—	—	34	16–18
11	9	5.1	54.9	800	6.9	47	8.4	14.3	77.7	—	—	—	34	16–18

TABLE VI.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge					Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH	Temperature, ° F.		Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Solid Content: 7.0 to 7.6%														
12	9	7.0	55.3	680	7.0	41	10.5	16.3	76.8	139	138	—	48	16–19
13	6	7.0	55.3	680	7.0	41	8.8	18.6	77.2	107	90	3.9	48	17–19
14	7	7.4	55.0	660	7.0	41	6.6	18.5	77.2	75	48	5.7	48	17–18
15	10	7.4	55.0	660	7.0	41	4.9	10.4	77.3	57	55	5.8	93	17–19
16	7	7.6	56.2	680	7.0	41	7.2	20.1	77.4	85	49	5.7	48	18–19
17	15	7.6	56.2	680	7.0	41	4.0	5.8	76.8	43	78	6.4	142	18–19
Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge (a) Solid Content: 2.9 to 3.1%														
18	10	3.1	54.4	230	7.0	—	7.9	8.0	72.2	54	48	—	62	18–19
19	10	3.1	54.4	230	7.0	—	5.3	11.0	72.3	27	32	5.3	38	19
20	10	2.9	53.8	230	7.0	—	2.9	3.6	72.1	15	14	5.9	132	19–20
21	10	2.9	53.8	230	7.0	—	4.3	6.9	72.1	34	34	5.4	62	19
22	10	2.9	53.4	230	7.0	—	7.1	6.6	72.0	14	20	5.0	62	17–18

(a) Sludge was elutriated in 2 steps. Elutriate from 1st step contained 200 p.p.m. amino-ammonia nitrogen, 202 p.p.m. B.O.D. (5 days at 20° C.), 282 p.p.m. suspended solids and had a pH value of 7.3. Elutriate from 2nd step contained 120 p.p.m. amino-ammonia nitrogen, 78 p.p.m. B.O.D. (5 days at 20° C.), 99 p.p.m. suspended solids and had a pH value of 7.2.

TABLE VI.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge: Solid Content, %	Digested Sludge: Volatile Matter, %	Digested Sludge: Amino-Ammonia Nitrogen, P.P.M.	Digested Sludge: pH	Digested Sludge: Temperature, ° F.	Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake: Dry Solids per Sq. Ft. of Filter Area per Hr., Lb.	Cake: Moisture, %	Effluent: B.O.D. 5-day at 20° C., P.P.M.	Effluent: Suspended Solids, P.P.M.	Effluent: pH	Filter Operation: Speed, Sec. per Rev.	Filter Operation: Vacuum, In.
Solid Content: 3.6%														
23	6	3.6	53.7	200	6.8	—	10.1	12.7	72.5	82	149	—	32	19
24	6	3.6	53.7	200	6.8	—	6.7	14.0	74.2	55	117	3.7	25	19
25	5	3.6	54.8	180	7.0	—	5.1	13.9	73.5	38	84	4.7	34	19
26	5	3.6	54.8	180	7.0	—	3.4	12.9	74.0	18	64	5.7	34	19
Solid Content: 5.6 to 5.8%														
27	5	5.8	55.0	300	6.7	41	6.3	23.1	76.4	99	61	4.5	28	18–19
28	9	5.8	55.0	300	6.7	41	2.7	13.4	76.1	32	38	5.5	60	18–19
29	5	5.6	55.2	300	6.7	41	4.9	22.0	77.0	53	52	5.5	30	18–19
30	5	5.6	55.2	300	6.7	41	6.1	25.5	77.8	59	73	4.9	25	19–20
31	10	5.6	55.3	300	6.7	41	2.2	6.2	75.2	16	67	6.3	113	18–19
Solid Content: 7.1 to 7.6%														
32	5	7.1	54.5	270	6.8	—	5.1	25.8	77.1	91	69	5.1	34	18
33	6	7.1	54.5	270	6.8	—	6.9	25.6	77.5	93	138	—	34	18–19
34	6	7.6	54.7	270	6.8	—	3.2	21.8	77.9	54	87	5.5	40	19–20
35	10	7.6	54.7	270	6.8	—	1.6	7.0	77.1	30	70	6.0	150	18–19
36	5	7.4	54.6	270	6.8	—	5.8	30.5	78.0	103	93	5.1	31	18–19

risul) and Calcoag (which contains 75 per cent ferric sulphate). The first series of results, given in Table VII and Figure 7, show that the

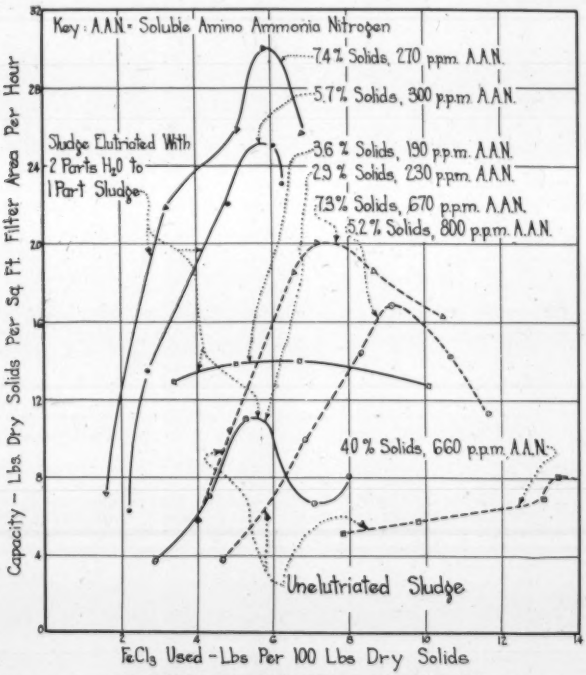

Key: A.A.N. - Soluble Amino Ammonia Nitrogen
7.4 % Solids, 270 p.p.m. A.A.N.
5.7 % Solids, 300 p.p.m. A.A.N.
Sludge Elutriated With 2 Parts H_2O to 1 Part Sludge
3.6 % Solids, 190 p.p.m. A.A.N.
2.9 % Solids, 230 p.p.m. A.A.N.
7.3 % Solids, 670 p.p.m. A.A.N.
5.2 % Solids, 800 p.p.m. A.A.N.
4.0 % Solids, 660 p.p.m. A.A.N.
Unelutriated Sludge
Capacity - Lbs. Dry Solids Per Sq. Ft. Filter Area Per Hour
$FeCl_3$ Used - Lbs Per 100 Lbs Dry Solids
EFFECT OF PER CENT SOLIDS IN SLUDGE ON FILTER CAPACITY
Series No 2

FIG. 6.

highest capacities, when dewatering unelutriated sludge, were obtained with ferric chloride. Chlorinated copperas gave a lower capacity; ferric sulphate was still lower; and Calcoag gave the poorest results. When expressed quantitatively, the amounts of coagulants needed per 100 lb. of dry solids to produce 8 lb. of dry cake per square foot of filter area were as follows: $FeCl_3$, 5.0 lb.; chlorinated copperas, 6.7 lb.; $Fe_2(SO_4)_3$,

TABLE VII.—*Effect of $FeCl_3$, Chlorinated Copperas, $Fe_2(SO_4)_3$ and Calcoag on Filtering Unelutriated and Elutriated Digested Sludge.*

Series No. 1

(Tests made November 20–December 5, 1933)

Test No.	Duration of Test, Min.	Digested Sludge				Anhydrous Coagulant Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Unelutriated													
Coagulant Used: $FeCl_3$													
1	6	7.4	52.9	800	6.9	8.2	27.1	75.4	—	—	—	30	16–17
2	7	7.4	52.9	800	6.9	6.6	27.2	74.8	—	—	—	28	16–18
3	20	6.7	54.0	750	6.9	5.5	10.5	73.3	—	—	—	100	18–19
4	20	6.7	54.0	750	6.9	4.6	6.2	74.8	—	—	—	140	17–18
5	8	6.9	54.0	760	6.9	10.7	27.6	74.0	—	—	—	28	16–18
Coagulant Used: Chlorinated Copperas													
6	10	7.2	52.3	850	6.9	8.0	15.6	75.1	—	—	—	40	18–19
7	20	7.2	52.3	850	6.9	6.4	6.7	73.9	—	—	—	110	17–18
8	8	7.2	52.7	830	7.0	9.7	20.6	76.1	—	—	—	25	15–17
9	9	7.2	52.7	830	7.0	11.3	20.2	76.5	—	—	—	25	15–17
10	9	7.2	53.7	810	7.0	10.4	19.7	75.4	—	—	—	25	15–17

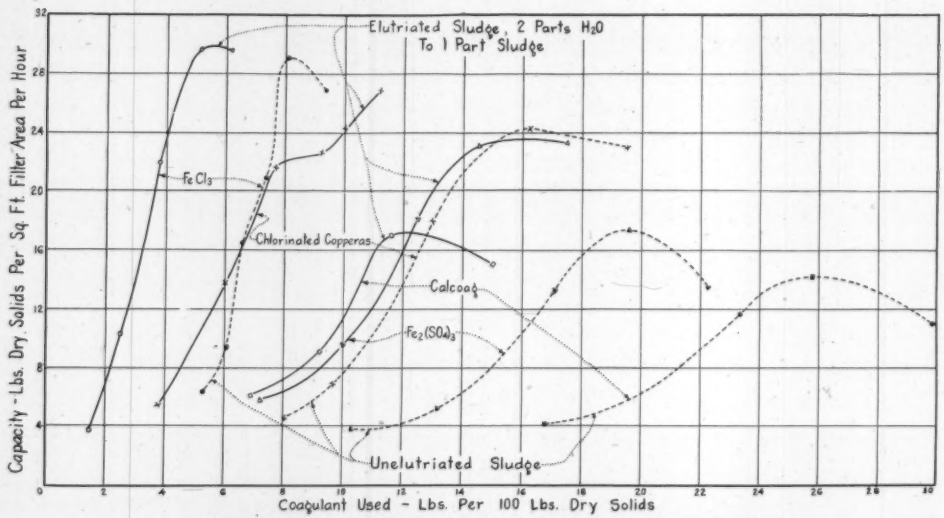
TABLE VII.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge				Anhydrous Coagulant Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Coagulant Used: $Fe_2(SO_4)_3$													
11	15	7.2	53.7	810	7.0	6.3	3.2	76.9	—	—	—	140	17–18
12	20	7.1	52.6	810	6.9	10.3	5.5	72.8	—	—	—	140	17–18
13	14	7.1	52.6	810	6.9	15.4	13.6	75.2	—	—	—	34	16–18
14	10	6.4	53.2	800	6.9	21.3	16.0	75.0	—	398	3.3	25	15–17
15	6.4	6.4	53.2	800	6.9	28.4	14.5	74.7	—	—	—	25	15–17
Coagulant Used: Calcoag													
16	7	6.5	53.6	790	6.9	20.9	8.8	75.5	—	—	—	40	14–16
17	18	6.5	53.6	790	6.9	13.9	6.6	73.3	—	—	—	100	14–19
18	15	6.8	53.7	770	6.9	9.4	4.4	75.6	58	52	7.0	140	14–19
19	8	6.8	53.7	770	6.9	26.9	10.2	74.6	150	904	4.3	48	15–17
Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge (a) Coagulant Used: $FeCl_3$													
20	4	6.4	54.8	280	6.6	5.7	30.5	75.9	79	156	4.9	25	18–19
21	5	6.4	54.8	280	6.6	3.8	22.5	75.1	—	—	—	34	18–19
22	10	6.4	54.9	270	6.7	1.9	9.3	75.8	—	—	—	100	18–19
23	15	6.4	54.9	270	6.7	1.6	5.8	75.5	22	82	6.5	152	17–18
24	5	6.4	54.4	270	6.7	6.7	27.0	75.8	—	—	—	25	18–19
25	5	6.4	54.4	270	6.7	4.8	28.0	76.1	—	—	—	25	18–19

(a) Sludge was elutriated in 2 steps. Elutriate from 1st step contained 430 p.p.m. amino-ammonia nitrogen, 208 p.p.m. B.O.D. (5 days at 20° C.), and 273 p.p.m. suspended solids. Elutriate from 2nd step contained 120 p.p.m. amino-ammonia nitrogen, 134 p.p.m. B.O.D. (5 days at 20° C.), 400 p.p.m. suspended solids and had a pH value of 7.3.

TABLE VII.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge				Anhydrous Coagulant Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Coagulant Used: Chlorinated Copperas													
26	4	6.6	56.4	210	6.7	6.9	28.6	75.1	—	—	—	25	17–18
27	7	6.6	56.4	210	6.7	5.2	21.3	74.9	—	—	—	34	17–18
28	8	5.9	54.9	250	6.8	3.8	15.3	74.8	—	—	—	58	17–19
29	15	5.9	54.9	250	6.8	1.9	4.6	74.7	20	78	6.4	147	17–19
30	6	6.0	55.5	250	6.8	9.5	23.4	75.6	108	262	3.0	25	17–18
31	5	6.0	55.5	250	6.8	6.7	24.7	76.4	—	—	—	25	17–18
Coagulant Used: $Fe_2(SO_4)_3$													
32	7	6.2	54.6	270	6.5	14.8	21.7	75.2	—	—	—	25	17–18
33	7	6.2	54.6	270	6.5	19.2	21.8	75.1	88	184	3.3	25	17–18
34	10	6.0	54.1	240	6.5	10.6	11.6	74.3	—	—	—	60	17–18
35	15	6.0	54.1	240	6.5	7.6	7.5	74.2	188	57	5.5	113	17–18
36	6	5.9	54.8	220	6.6	17.7	23.7	75.5	—	—	—	25	17–18
Coagulant Used: Calcoag													
37	6	6.0	54.1	250	6.4	15.2	20.9	77.0	45	200	4.5	25	18–19
38	6	6.0	54.1	250	6.4	12.2	22.1	77.1	—	—	—	25	17–19
39	7	5.9	54.0	220	6.4	9.2	18.1	76.5	—	—	—	34	17–19
40	10	5.9	54.0	220	6.4	6.1	12.4	75.5	—	—	—	60	18–20
41	6	6.0	53.3	250	6.4	3.0	3.7	76.1	40	82	6.1	152	17–19
42	7	6.0	53.3	250	6.4	13.6	18.0	77.7	—	—	—	34	17–19


Elutriated Sludge, 2 Parts H_2O To 1 Part Sludge
$FeCl_3$
Chlorinated Copperas
Calcoag
$Fe_2(SO_4)_3$
Unelutriated Sludge
Capacity - Lbs. Dry Solids Per Sq. Ft. Filter Area Per Hour
Coagulant Used - Lbs. Per 100 Lbs. Dry Solids
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
4 8 12 16 20 24 28 32

EFFECT OF $FeCl_3$, $Fe_2(SO_4)_3$, CALCOAG AND CHLORINATED COPPERAS ON FILTERING ELUTRIATED AND UNELUTRIATED SLUDGE

Series No. 2

FIG. 7.

TABLE VIII.—*Effect of $FeCl_3$, Chlorinated Copperas, $Fe_2(SO_4)_3$ and Calcoag on Filtering Unelutriated and Elutriated Digested Sludge.*

Series No. 2

(Tests made April 9–13, 1934)

Test No.	Duration of Test, Min.	Digested Sludge				Anhydrous Coagulant Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Unelutriated													
Coagulant Used: $FeCl_3$													
1	9	7.0	53.1	950	7.2	6.6	16.4	76.9	—	—	—	48	15–18
2	10	7.0	53.1	950	7.2	5.3	6.4	76.8	52	103	5.9	145	17–18
3	6	6.9	53.3	950	7.3	8.1	29.1	77.6	82	113	5.5	25	16–19
4	6	6.9	53.3	950	7.3	9.4	26.8	77.0	—	—	—	25	16–18
5	7	6.9	53.4	950	7.1	7.4	20.7	77.8	—	—	—	33	16–18
6	10	6.9	53.4	950	7.1	6.1	9.3	76.1	—	—	—	115	16–18
Coagulant Used: Chlorinated Copperas													
7	10	6.9	54.0	950	7.3	8.1	4.5	77.1	—	194	6.0	192	17–19
8	10	6.9	54.0	950	7.3	9.8	6.9	76.3	—	—	—	133	17–18
9	6	6.9	53.9	930	7.1	13.0	18.0	76.6	—	—	—	40	16–18
10	6	6.9	53.9	930	7.1	16.2	24.4	77.3	—	126	5.2	25	17–19
11	6	6.9	54.3	960	7.0	19.5	23.1	76.5	—	—	—	25	16–18

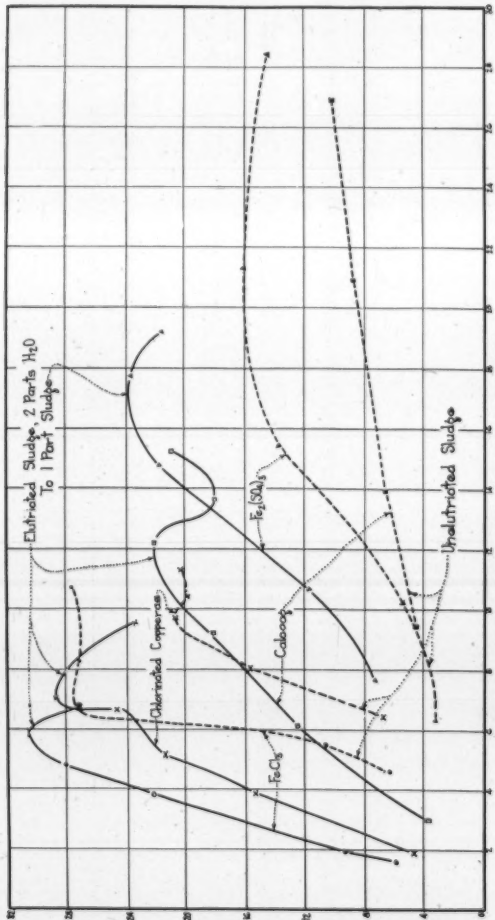
TABLE VIII.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge				Anhydrous Coagulant Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Coagulant Used: $Fe_2(SO_4)_3$													
12	10	6.9	54.0	940	7.0	17.1	13.3	76.0	118	235	5.3	52	17–19
13	10	6.9	54.6	940	7.1	13.2	5.2	75.8	79	146	5.8	108	16–19
14	9	6.9	53.4	920	7.1	19.6	17.5	77.2	—	—	—	24	17–18
15	10	6.9	53.4	920	7.1	22.3	13.5	75.9	—	—	—	36	17–18
16	10	7.0	53.7	930	7.1	10.3	3.8	76.4	—	—	—	186	17–19
Coagulant Used: Calcoag													
17	10	7.0	53.7	930	7.1	16.8	4.1	74.5	126	203	5.8	141	17–18
18	10	7.0	53.2	920	7.1	23.4	11.6	75.4	—	—	—	47	16–17
19	10	7.0	53.2	920	7.1	30.0	11.6	74.9	—	—	—	32	16–17
20	10	7.0	53.2	920	7.1	25.9	14.2	77.8	139	353	3.8	32	16–18
Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge (a) Coagulant Used: $FeCl_3$													
21	5	7.3	53.8	400	7.0	5.1	29.7	78.5	129	195	5.9	26	18–19
22	7	7.4	53.8	400	6.9	3.8	21.9	76.5	—	—	—	44	17–19
23	10	7.4	53.8	400	6.9	2.5	10.3	77.3	49	36	5.3	97	17–19
24	5	7.5	53.8	400	7.0	6.2	29.6	78.1	—	—	—	26	17–19
25	10	7.5	53.8	400	7.0	1.5	3.7	81.8	—	—	—	188	18–19

(a) Sludge was elutriated in 2 steps. Elutriate from 1st step contained 550 p.p.m. amino-ammonia nitrogen, 267 p.p.m. B.O.D. (5 days at 20° C.), 436 p.p.m. suspended solids and had a pH value of 7.3. Elutriate from 2nd step contained 180 p.p.m. amino-ammonia nitrogen, 147 p.p.m. B.O.D. (5 days at 20° C.), 452 p.p.m. suspended solids and had a pH value of 7.5.

TABLE VIII.—*Continued*

Test No.	Duration of Test, Min.	Digested Sludge				Anhydrous Coagulant Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Coagulant Used: Chlorinated Copperas													
26	7	7.3	53.8	400	6.9	7.7	21.6	77.3	94	196	—	38	17–19
27	7	7.3	53.8	400	6.9	9.2	22.6	78.0	—	—	—	38	17–19
28	10	7.4	53.4	380	6.9	6.1	13.7	76.5	—	—	—	65	17–19
29	10	7.4	53.4	380	6.9	3.8	5.4	75.5	34	68	—	188	16–18
30	6	7.5	53.7	390	6.9	11.2	26.8	78.8	—	—	—	25	17–19
31	7	7.5	53.7	390	6.9	10.0	24.2	78.7	—	—	—	25	18–19
Coagulant Used: $Fe_2(SO_4)_3$													
32	9	7.3	53.6	400	7.0	12.5	18.1	76.6	144	281	3.9	38	17–19
33	10	7.3	53.6	400	7.0	10.0	9.4	75.4	—	—	—	85	17–19
34	8	7.5	54.5	400	7.0	14.5	23.2	77.6	—	—	—	26	18–19
35	10	7.5	54.5	400	7.0	7.2	5.9	74.3	81	85	4.9	148	18–19
36	7	7.3	53.8	400	7.0	17.5	23.4	78.3	—	—	—	26	17–19
Coagulant Used: Calcoag													
37	10	7.8	53.3	380	6.9	11.6	17.2	78.3	110	171	—	38	17–19
38	10	7.8	53.3	380	6.9	9.3	9.0	75.9	—	—	—	82	16–18
39	10	7.9	52.8	360	6.8	6.9	6.1	75.3	64	—	—	188	17–19
40	10	7.9	52.8	360	6.8	15.0	15.1	78.4	—	—	—	33	17–19


Capacity - Lbs. Dry Solids Per Sq. Ft. Filter Area Per Hour
Coagulant Used - Lbs. Per 100 Lbs. Dry Solids
Elutriated Sludge, 2 Parts H2O To 1 Part Sludge
Chlorinated Copperas
Fe2Cl6
Caloag
Fe2(SO4)3
Unelutriated Sludge

EFFECT OF Fe_2Cl_6, $Fe_2(SO_4)_3$, CALCOAG AND CHLORINATED COPPERAS ON FILTERING ELUTRIATED AND UNELUTRIATED SLUDGE

Series No. I

FIG. 8.

12.2 lb.; and Calcoag, 18.5 lb. After the sludge had been elutriated with two parts of water to one part of sludge in two stages, the quantities of coagulants required to produce this same quantity were: $FeCl_3$, 1.8 lb.; chlorinated copperas, 2.5 lb.; Calcoag, 4.3 lb.; and $Fe_2(SO_4)_3$, 8.4 lb. The amino-ammonia nitrogen varied from 750 to 850 p.p.m. in the unelutriated sludge and from 210 to 280 p.p.m. in the elutriated material.

The results of a second series of experiments using these same coagulants are shown in Table VIII and Figure 8. In this case both the unelutriated and the elutriated sludges were harder to dewater than the materials filtered in the first series. The reason was that the concentrations of compounds containing amino-ammonia nitrogen in the unelutriated and elutriated sludges filtered in the second series were about 150 p.p.m. higher than those in the first series. This higher concentration of amino-ammonia nitrogen required only slightly more ferric chloride to produce the same filter capacity, whereas much larger amounts of the other three coagulants were needed, except that ferric sulphate gave about the same capacities when filtering the elutriated sludge. With the possible exception of ferric chloride the maximum productions when using the other coagulants were greatest when filtering the elutriated sludges.

Dewatering Raw Sludge.—As there has been considerable interest within the past year or two in the filtration and incineration of raw sludge, it was considered desirable to run a few tests on such material. This work was supplemented by dewatering a mixture of equal volumes of raw and digested solids. The results are given in Table IX and Figure 9. First, digested sludge containing about 990 p.p.m. of amino-ammonia nitrogen was dewatered. A portion of the same material was elutriated in two steps, with two volumes of water to one volume of sludge, and filtered.

Then unelutriated raw sludge with an amino-ammonia nitrogen content of about 320 p.p.m. was dewatered. The output was quite low, the maximum being 4.1 lb. of dry solids per square foot of filter area per hour when using 2.9 lb. of anhydrous ferric chloride per 100 lb. of dry solids. The effluent had a high 5-day B.O.D. of 1,006 p.p.m. in one sample and 1,889 p.p.m. in the other. As was to be expected, the odor of the cake was very unpleasant.

Equal volumes of raw and unelutriated digested sludge were then mixed and filtered. The presence of the raw solids greatly reduced the filter capacity as compared with the yield when dewatering unelutriated digested sludge. A maximum capacity of 6.5 lb. of dry solids per square foot of filter area per hour was obtained when using 5.1 lb. of ferric chloride per 100 lb. of dry solids. Two samples of the effluent had a 5-day B.O.D. of 672 and 449 p.p.m.

TABLE IX.—*Effect of Mixing Raw and Digested Sludge on Filter Capacity*
(Coagulant Used: $FeCl_3$. Tests made May 7–11, 1934)

Test No.	Duration of Test, Min.	Sludge				Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Unelutriated—Digested Sludge													
1	5	7.8	54.0	980	7.2	8.4	28.3	76.2	158	97	5.0	33	15–18
2	9	7.8	54.0	980	7.2	6.0	20.0	78.2	—	—	—	42	15–19
3	10	7.9	54.0	980	7.2	4.7	7.5	76.9	53	115	6.5	154	19–20
4	7	7.9	54.0	980	7.2	7.1	23.4	77.1	—	—	—	36	17–18
5	5	8.0	54.4	1000	7.2	9.4	31.8	78.8	—	—	—	25	18–19
6	5	8.0	54.4	1000	7.2	10.5	33.7	77.3	—	—	—	25	18–19
Raw Sludge													
7	10	6.4	73.5	330	5.6	2.9	4.1	75.2	1006	79	4.1	207	20
8	10	6.3	76.0	320	5.6	4.4	3.7	73.8	—	—	—	207	18–20
9	10	6.3	76.0	320	5.6	5.9	2.9	74.9	—	—	—	207	20
10	10	6.2	77.4	310	5.6	3.7	3.5	75.3	1889	50	3.3	207	20
11	10	6.2	77.4	310	5.6	2.2	2.6	74.7	—	—	—	269	19–20
Mixture of 1 Volume of Raw with 1 Volume of Digested Sludge													
12	10	7.0	64.9	620	6.4	6.7	4.3	76.0	672	57	4.1	266	20
13	10	7.0	64.9	620	6.4	8.0	5.1	76.1	—	—	—	177	20
14	10	7.3	62.3	700	6.5	5.1	6.5	75.5	—	—	—	120	19–20
15	10	7.3	62.3	700	6.5	3.8	4.8	77.3	449	49	5.1	177	19–20
16	10	7.0	65.7	610	6.5	6.0	6.1	77.4	—	—	—	120	18–19
17	10	7.0	65.7	610	6.5	4.6	4.8	76.8	—	—	—	213	19

TABLE IX.—*Continued*

Test No.	Duration of Test, Min.	Sludge: Solid Content, %	Sludge: Volatile Matter, %	Sludge: Amino-Ammonia Nitrogen, P.P.M.	Sludge: pH	Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake: Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Cake: Moisture, %	Effluent: B.O.D. 5-day at 20° C., P.P.M.	Effluent: Suspended Solids, P.P.M.	Effluent: pH	Filter Operation: Speed, Sec. per Rev.	Filter Operation: Vacuum, In.
Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge (a)													
Digested Sludge													
18	10	7.7	55.5	280	6.9	2.4	11.4	76.9	175	51	5.3	89	18–20
19	8	7.7	55.5	280	6.9	3.6	22.0	77.8	—	—	—	42	19–20
20	5	7.8	55.1	320	6.9	4.8	31.8	79.2	150	54	5.1	23	20
21	5	7.8	55.2	310	6.8	5.4	34.0	78.5	—	—	—	23	20
22	10	7.8	55.2	310	6.8	1.4	6.1	75.8	—	—	—	185	19–20
Mixture of 1 Volume of Unelutriated Raw with 1 Volume of Elutriated Digested Sludge													
23	8	6.8	63.6	340	5.5	4.1	15.2	76.8	67	103	4.5	52	20–21
24	10	6.8	63.6	340	5.5	2.7	9.1	76.1	—	—	—	87	18–20
25	10	6.8	64.7	330	5.5	1.4	3.1	75.1	38	58	5.1	216	19–20
26	10	6.8	64.7	330	5.5	4.8	13.4	77.6	—	—	—	32	20
27	9	6.8	63.9	280	5.5	3.4	14.0	78.1	—	—	—	32	20

(a) Digested sludge was elutriated in 2 steps. Elutriate from 1st step contained 87 p.p.m. B.O.D. (5 days at 20° C.), 50 p.p.m. suspended solids and had a pH value of 7.4. Elutriate from 2nd step contained 39 p.p.m. B.O.D. (5 days at 20° C.), 149 p.p.m. suspended solids and had a pH value of 7.3.

Although the amino-ammonia content of the digested sludge, which amounted to approximately 1,000 p.p.m., was reduced when mixed with the raw material having about 300 p.p.m. of amino-ammonia nitrogen,

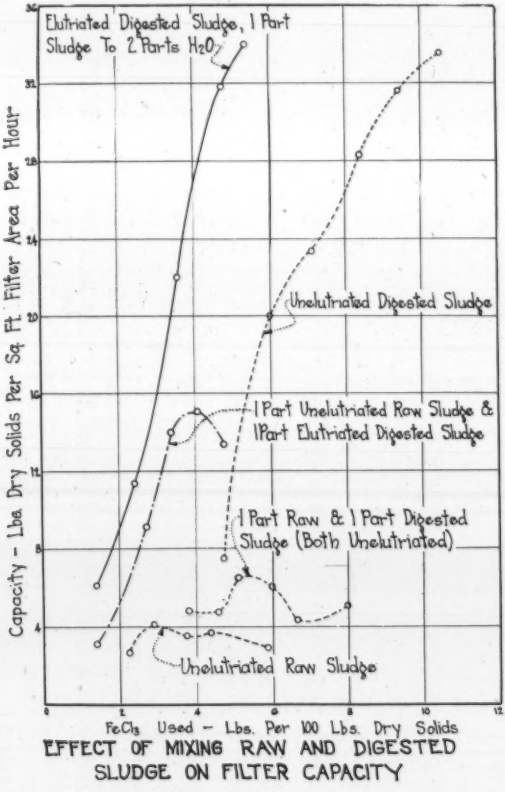

Elutriated Digested Sludge, 1 Part Sludge To 2 Parts H_2O
Unelutriated Digested Sludge
1 Part Unelutriated Raw Sludge & 1 Part Elutriated Digested Sludge
1 Part Raw & 1 Part Digested Sludge (Both Unelutriated)
Unelutriated Raw Sludge
Capacity - Lbs. Dry Solids Per Sq. Ft. Filter Area Per Hour
$FeCl_3$ Used - Lbs. Per 100 Lbs. Dry Solids
EFFECT OF MIXING RAW AND DIGESTED SLUDGE ON FILTER CAPACITY

FIG. 9.

the coagulant consumption when compared with that of raw sludge was not decreased; and, as previously stated, the filtration rate of the mixture was quite low. Apparently some chemical in the raw sludge

combined with the ammoniacal compounds in the unelutriated digested material to form other ammoniacal compounds, which reacted with ferric chloride so that the mixture filtered little better than raw sludge. Genter claims that this condition is due in all probability to carbamino compounds forming from amino acids, which are found in raw sludge, and carbonic acid in digested material. Such compounds have quite a chemical affinity for ferric and other metal ions.

When elutriated digested sludge, which contained a comparatively small amount of ammonium bicarbonate, was mixed with an equal volume of raw sludge, much different results were obtained. This mixture gave a much higher filtration rate than unelutriated digested or raw sludge or a mixture of the two. The oxygen demand of the effluent was quite low, with a 5-day B.O.D. of 38 p.p.m. in one sample and 67 p.p.m. in the other. The odor of the cake was much less than when raw sludge alone was filtered. Some of the material was stored in the laboratory for a few days, at the end of which time it had an odor similar to dirty oyster shells. The raw sludge used in the above tests was not fresh, but was 5 or 6 days old. If this material had been only two or three hours old, with an amino-ammonia nitrogen content of about 100 p.p.m. or less, it is possible that even higher filtration rates would have resulted with the use of less coagulant. Unfortunately, the treatment units at the sewage works are such that it is impossible to get a sufficient quantity of fresh sludge so that the laboratory work could be verified on a large scale.

The low maximum filtration rates when dewatering raw sludge are believed to be due to the amino-acid and amino compounds present. When fresh sludge, which was about 1½ hr. old and had an amino-ammonia nitrogen content of 50 to 100 p.p.m., was dewatered in a Buechner funnel, maximum filtration rates equal to those of digested sludge were obtained, except that less ferric chloride was needed because of the lower amino-ammonia nitrogen content. As raw sludge decomposes from day to day, the amino-ammonia nitrogen increases. One sample of fresh solids, which was collected over a period of 18 hr., contained 45 p.p.m. of amino-ammonia nitrogen. At the end of 10 days the amino-ammonia nitrogen had increased to 491 p.p.m. The amount of coagulant required to flocculate such decomposing sludges increases in direct proportion to the increase in amino-ammonia nitrogen, and the maximum filtration rates decrease.

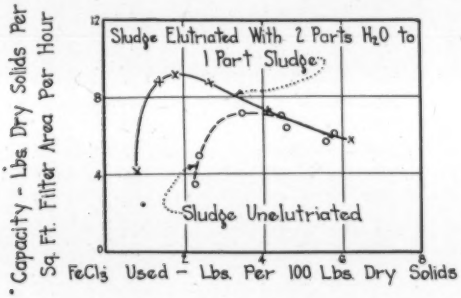
A second group of experiments, the results of which are shown in Table X and Figure 10, consisted of filtering unelutriated and elutriated raw sludge. Regardless of the amount of coagulant used, it was impossible to obtain the high capacities when dewatering raw material as compared with digested solids. The maximum cake output was 7.2 lb.

TABLE X.—*Filter Capacity When Dewatering Unelutriated and Elutriated Raw Sludge*
(Coagulant: $FeCl_3$. Tests made September 11–14, 1933)

Test No.	Duration of Test, Min.	Digested Sludge				Anhydrous $FeCl_3$ Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent		Filter Operation	
		Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture, %	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Sludge Unelutriated												
1	20	7.4	74.9	220	5.3	5.8	6.2	73.5	164	3.9	180	20
2	20	7.4	74.9	220	5.3	4.6	6.5	73.9	—	—	150	20
3	20	7.2	76.0	220	5.3	3.5	7.2	75.6	—	—	128	20
4	20	7.2	76.0	220	5.3	2.4	5.0	75.7	—	—	150	20
5	15	7.6	75.1	344	5.2	5.6	5.8	77.0	—	3.4	281	20
6	15	7.6	75.1	344	5.2	4.5	7.1	74.6	117	—	168	20
7	20	7.4	76.1	344	5.2	2.3	3.5	76.8	93	4.4	320	20
Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge (a)												
8	15	6.2	75.9	134	—	6.2	5.8	75.5	—	—	150	21
9	15	6.2	75.9	134	—	4.1	7.3	74.8	95	—	105	21
10	15	7.0	77.4	134	—	2.7	8.7	75.3	47	—	85	21
11	15	7.0	77.4	134	—	1.8	9.1	74.6	—	—	67	20
12	15	6.9	72.9	134	—	1.4	8.8	75.1	—	—	67	20
13	15	6.9	72.9	134	—	0.8	4.2	74.4	44	—	167	20

(a) Sludge was elutriated in one step. Elutriate contained 120 p.p.m. amino-ammonia nitrogen and 243 p.p.m. suspended solids.

of dry solids per square foot of filter area per hour when dewatering unelutriated sludge and 9.1 lb. when filtering elutriated solids. Even though the capacities were low, it was possible to flocculate the raw sludge with small quantities of coagulant, which quantities would have given unsatisfactory results if used with the digested material. The



EFFECT OF ELUTRIATING FRESH SLUDGE ON FILTER CAPACITY

FIG. 10.

reason for this condition undoubtedly was because of the low concentration of amino-ammonia nitrogen, which varied from 220 to 344 p.p.m. before elutriation and was 134 p.p.m. after elutriation.

Duration Tests.—Although the chemical and physical characteristics of the digested sludges varied during the tests, the results given in each table were obtained on the same batch of material, the consistency of which was kept uniform by stirring. It was desirable to follow this procedure so that the variable factors which affect the quantity of cake produced would be reduced to a minimum. Since as many as 44 separate filtration tests were made on the same sludge, each had to be of short duration.

It was considered advisable, therefore, to make several filtration tests with elutriated sludge for longer periods of time and with a constant quantity of coagulant during each test. Six runs in all were made (see Table XI), three with ferric chloride and three with chlorinated copperas. Each run lasted from 2½ to 5 hr.; two were made with each coagulant when using a small dosage. The other two runs were with large dosages in order to produce high yields. When using 2.0 lb. of

TABLE XI.—*Filter Capacity When Dewatering Elutriated Digested Sludge*
Sludge Elutriated with 2 Volumes of Water to 1 Volume of Sludge

Test No.	Date	Duration of Test, Hr.	Digested Sludge				Elutriate				Anhydrous Coagulant Used per 100 Lb. Dry Solids, Lb.	Cake		Effluent			Filter Operation	
			Solid Content, %	Volatile Matter, %	Amino-Ammonia Nitrogen, P.P.M. %	pH	B.O.D. 5-day at 20° C., P.P.M.	Amino-Ammonia Nitrogen, P.P.M.	Suspended Solids, P.P.M.	pH		Dry Cake per Sq. Ft. of Filter Area per Hr., Lb.	Moisture %	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	pH	Speed, Sec. per Rev.	Vacuum, In.
Coagulant: $FeCl_3$																		
1	November 15, 1933	5	6.4	54.6	230	6.7	— 148	290 140	246 298	8.0(a) 8.0(b)	2.6	8.2	74.3	34	85	6.4	93	17–19
2	March 28, 1934	5	6.7	55.1	190	6.8	196 128	— —	550 161	— (a) — (b)	2.0	5.2	76.1	25	59	—	134	18–20
3	May 2, 1934	3	7.6	55.0	360	6.9	150 112	— 160	82 85	7.4(a) 7.3(b)	4.6	28.7	78.0	95	79	5.4	26	20
Coagulant: Chlorinated Copperas																		
4	May 17, 1934	5	7.7	54.1	280	6.9	93 53	400 200	76 76	7.4(a) 7.5(b)	4.1	6.4	74.9	66	60	5.7	160	17–20
5	May 22, 1934	5	7.6	53.6	210	6.8	— 86	— —	— 100	— (a) 7.6(b)	4.2	9.1	75.6	52	46	5.5	113	18–19
6	May 31, 1934	2.5	6.7	53.8	200	6.7	129 88	410 150	138 79	7.5(a) 7.4(b)	6.5	20.6	77.9	108	74	5.1	33	19–20

(a) Chemical characteristics of elutriate from first step. (b) Chemical characteristics of elutriate from second step.

anhydrous ferric chloride per 100 lb. of dry solids, 5.2 lb. of dry solids per square foot of filter area per hour was produced; and when 4.6 lb. of coagulant was used, the capacity was 28.7 lb. A yield of 6.4 lb. of cake was obtained when using 4.1 lb. of anhydrous chlorinated copperas. This production was increased to 20.6 lb. with an application of 6.5 lb. of chlorinated copperas.

Elutriating Water.—All of the water used to elutriate the sludge in these tests was obtained from the Baltimore City water supply. This water contained no amino-ammonia nitrogen. Practically as good results were obtained when using primary tank effluent during some preliminary tests. Twenty-seven samples of this effluent have been found to have an average amino-ammonia nitrogen content of 15 p.p.m.

Most of the experiments were with sludge that had been elutriated with two volumes of water. Whether a greater economy can be effected by using more water remains to be seen. More ammoniacal compounds would be dissolved out of the sludge, and less coagulant would be required if larger quantities of water were used. This saving in coagulant, however, would be offset by the necessity of using larger elutriating tanks with additional facilities for handling the increased volume of elutriate.

The mixing of the sludge and the water requires only a few minutes, and can be accomplished by means of compressed air or mechanical stirring devices. As previously stated, the mixture of sludge and water settled from 17 to 48 hours. As a result of laboratory investigations, it seems probable that much shorter sedimentation periods, ranging from about 4 to 6 hours, can be used. However, the longer the sedimentation time, the more dense the sludge will become. It should also be possible to reduce the period of sedimentation by equipping the elutriating tanks with mechanical thickeners. The sludge can be elutriated by the fill-and-draw or by the continuous-flow method. One of the advantages of the continuous-flow method is that, where the elutriated sludge and the elutriate have to be pumped, the head pumped against will frequently be less. Studies are now being made at the Baltimore sewage works to obtain additional information regarding some of the above questions.

The volume, character and method of treating the elutriate are of vital importance. If two volumes of elutriating water are used with one volume of sludge, it is estimated that 292,000 gal. of elutriate will be produced daily at the Baltimore sewage works. This quantity is based on the elutriation of 73,000 lb. of dry solids daily, containing 94.0 per cent water, for 300 days a year. The chemical and physical characteristics of the elutriate are given in Table XII when one volume of digested sludge is elutriated with two volumes of water in two equal stages. These results have been obtained from the previous tables, and assembled for

ease of comparison. As indicated, the elutriate from a mixture of two volumes of water with one volume of digested sludge, when the process is in two equal stages, has been found to have the following characteristics: 5-day B.O.D. at 20° C., 158 p.p.m.; suspended solids, 270 p.p.m.; and amino-ammonia nitrogen, 251 p.p.m.

TABLE XII.—*Chemical Characteristics of Elutriate from a Mixture of Two Volumes of Water and One Volume of Sludge*

Test No.	Elutriate from 1st Stage, Equal Volumes of Water and Sludge Mixed			Elutriate from 2nd Stage, Equal Volumes of Water and Sludge Mixed		
	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	Amino-Ammonia Nitrogen, P.P.M.	B.O.D. 5-day at 20° C., P.P.M.	Suspended Solids, P.P.M.	Amino-Ammonia Nitrogen, P.P.M.
1	—	600	280	—	—	—
2	582	922	220	107	382	150
3	202	282	200	78	99	120
4	208	273	430	134	400	120
5	267	436	550	147	452	180
6	—	246	290	148	298	140
7	196	550	—	128	161	—
8	150	82	—	112	85	160
9	93	76	400	53	76	200
10	87	50	—	39	149	—
11	—	—	—	86	100	—
12	129	138	410	88	79	150
Average	213	332	348	102	207	153

Calculated average characteristics of a mixture of the elutriates from 1st and 2nd stages:

B.O.D.	158 P.P.M.
Suspended Solids	270 P.P.M.
Amino-Ammonia Nitrogen	251 P.P.M.

The most satisfactory way of treating the elutriate at the Baltimore sewage works would be to pump it into the raw sewage. The daily addition of 292,000 gal. of elutriate, containing a B.O.D. of 158 p.p.m., to a flow of 76.35 m.g.d. (1933 average) with a B.O.D. of 249 p.p.m. would be equivalent to increasing the B.O.D. load on the sewage works by 0.24 per cent.

The equipment used to remove the elutriate from the three sludge tanks, which consisted of 2-in. swivel pipes, was not of the best design. When these pipes were lowered to a point just above the surface of the

sludge, the elutriate entered the pipes in a vortex motion, and some sludge particles escaped with the elutriate. Furthermore, some of the sludges were more completely digested than others. The elutriates from the well digested materials contained less solids, and had lower biochemical oxygen demands.

Cost of Filtering Elutriated Sludge.—The ultimate purpose of sludge elutriation is to reduce the cost of sludge dewatering. This reduction is accomplished by the removal of a considerable portion of the amino-ammonia compounds, which normally enter into chemical combination with ferric chloride or other such coagulants when filtering unelutriated sludge. Elutriated sludge, therefore, requires less coagulant.

TABLE XIII.—*Comparative Estimates of Sludge Filter Installations*

Item	Estimate No. 1, 4–350 Sq. Ft. Filters Using 2½ Lb. of $FeCl_3$ per 100 Lb. of Dry Solids	Estimate No. 2, 4–350 Sq. Ft. Filters Using 4.1 Lb. of $FeSO_4Cl$ per 100 Lb. of Dry Solids
Installation Costs		
Building	$38,500	$38,500
Filtering equipment	64,000	64,000
Piping and valves	4,500	4,500
High tension power equipment	4,700	4,700
Out-door conveyor	1,500	1,500
Coagulant storage tanks	6,500	6,500
Elutriating tanks and piping	16,300	16,300
Sludge pumps and piping	3,000	3,000
Chlorinating equipment	—	5,000
Total	$139,000	$144,000
Operating Costs per Year		
Interest and depreciation	$12,390	$13,026
1 Operator	1,600	1,600
Coagulant	12,045	10,227
Electric current @ 1.9¢ per kw. hr	7,085	7,085
Pumping elutriate	1,300	1,300
Coal, oil, repairs, etc.	2,580	2,662
Total	$37,000	$35,900
Cost per ton of dry solids	$3.38	$3.28

Two estimates have been prepared on the cost of dewatering elutriated digested sludge at the Baltimore sewage works. These estimates are based on the filtration of sludge containing 30 tons of dry solids per day, or 36½ tons on the assumption that the filters will be operated 7¾ hr. per day for 300 days a year. The installation includes a building,

housing four 350-sq. ft. drum filters, together with the other necessary equipment such as compressors, vacuum, filtrate, elutriate and sludge pumps, 4 concrete elutriation tanks with a total working capacity of 58,500 cu. ft., piping, etc.

The first estimate is based on the use of 2½ lb. of anhydrous ferric chloride per 100 lb. of dry solids, with an output of 7.2 lb. of dry solids per square foot of filter area per hour. This capacity is about 12 per cent less than the output of 8.2 lb. of cake obtained when using 2.6 lb. of ferric chloride, as indicated in Table XI, Test No. 1. It was considered advisable to estimate on a somewhat lower capacity to allow for a factor of safety. This estimate includes the use of 547,000 lb. of anhydrous ferric chloride annually at a cost of 2.2c. per pound. As indicated in Table XIII, the total estimated cost of the filter installation with all accessories is $139,000. The annual operating and maintenance costs including fixed charges amount to $37,000, or $3.38 per ton of dry solids.

The costs when using chlorinated copperas as a coagulant instead of ferric chloride are given in Table XIII, Estimate No. 2. A filter capacity of 7.0 lb. of dry solids per square foot of filter area per hour when using 4.1 lb. of anhydrous chlorinated copperas per 100 lb. of dry solids has been assumed in determining the size of the filters. This capacity is 10 per cent less than the average of the capacities shown in Table XI, Tests 4 and 5.

Copperas can be obtained locally in Baltimore for $7.50 per ton. The estimated cost of making 1,000 lb. of anhydrous chlorinated copperas is

1,485 lb. of $FeSO_4.7H_2O$ @ $0.00375	$ 5.57
Hauling	.88
190 lb. of Cl_2 @ 2.6c.	4.94
	$11.39

The complete filter installation together with the necessary equipment for chlorinating the copperas (see Table XIII) is estimated to be $144,000, and the total cost of sludge filtration including all charges is $3.28 per ton of dry solids. In 1932 estimates [2] were prepared on the filtering of the Baltimore sludge before the elutriation process was fully developed. At that time the estimated cost of sludge filtration varied from $4.22 to $5.00 per ton of dry solids. If $4.61, which is the average of these two estimates, is used as a basis of comparison with Estimate No. 1, the adoption of the sludge elutriation process at Baltimore would mean an estimated annual saving of $13,500 as compared with the cost of filtering unelutriated sludge. In studying these estimates it should be remembered that present-day costs of building materials and filter equipment are from 10 to 20 per cent higher than in 1932.

But the saving is more pronounced when the cost of filtering elutriated sludge is compared with the expenditure necessary to dewater sludge on uncovered drying beds, the method used at present in Baltimore. The cost of air-drying sludge at Baltimore from 1925 to 1933, inclusive, has averaged $6.13 per ton of dry solids. Based on dewatering 30 tons of dry solids daily, the total yearly cost would be $67,100. As compared with this expenditure, an annual saving of $30,100 would result if the sludge were elutriated and filtered and ferric chloride were used as a coagulant, and $31,200 if chlorinated copperas were employed.

Conclusions

The filtering of elutriated sludge is a practicable method of dewatering the digested sludge at the Baltimore sewage works. The removal of the amino-ammonia compounds will permit the use of much less coagulant, with a saving of several thousand dollars annually. As the quantity of elutriate is small and as its 5-day B.O.D. is considerably less than that of the raw sewage at Baltimore, the problem of treating the elutriate should present no difficulties. The character of the filter cake is little different from the cake obtained from unelutriated sludge. In fact the former is somewhat more dense, as unelutriated digested sludge foams much more than elutriated material when a coagulant is added.

The experiments indicate the desirability of removing as large a quantity of the amino-ammonia nitrogen as possible. There is, however, a limit beyond which it is undesirable to go, as the saving in coagulant is offset by the greater cost of more extensive facilities for elutriating the sludge and handling the elutriate. Furthermore, the work has emphasized the desirability of filtering as concentrated a sludge as possible.

Four different coagulants were used in order to study their effect on the filtrability of unelutriated and elutriated sludge. Of these the greatest filter capacity was obtained when using ferric chloride. The next best results were with chlorinated copperas. Regardless of the coagulant used, higher capacities resulted when elutriated sludge was filtered. Although considerably more chlorinated copperas is needed than ferric chloride, the cost of the former in Baltimore is about one-half of the latter. An estimated saving of about $1,100 a year would result by using chlorinated copperas at Baltimore.

The increased capacities obtained by filtering elutriated raw sludge are not so great as when digested sludge is elutriated and dewatered. The reason is that raw sewage solids contain very much less amino-ammonia compounds, which are difficult to remove by elutriation. If raw sludge is to be dewatered, it should either be filtered when it is not more than a few hours old or mixed with elutriated digested sludge so that little coagulant need be used.

The elutriation of digested sludge offers a satisfactory means of greatly reducing the cost of sludge filtration formerly proposed for the Baltimore sewage works. If this process should prove equally successful as a means of treating digested sludges in other cities, it is believed that the process represents a considerable advance in the field of sludge dewatering.

Acknowledgments.—The sewage works is under the general control of B. L. Crozier, chief engineer, Department of Public Works, and George E. Finck, sewerage engineer, with G. K. Armeling, superintendent. Acknowledgments are due to the Oliver United Filters, Inc., who furnished the filter, the Carborundum Co., who furnished Aloxite tubes, used to add chlorine to the copperas, and the Pennsylvania Salt Manufacturing Co., the Calcoag Chemical Co., the E. I. duPont de Nemours and Co., and the Merrimac Chemical Co., who generously furnished the different coagulants and chemicals. Valuable assistance was rendered in the field and laboratory work by A. L. Genter, consulting chemical engineer, E. C. Cromwell, principal sanitary chemist, J. W. Bushman, Paul Smith and Henry Weiner, junior chemists.

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Discussion of Paper by Keefer and Kratz, "The Mechanical Filtration of Elutriated Sludge"

By E. B. Besselievre

The Dorr Company, Inc., New York

It matters little by what name a newly developed principle in engineering science is designated. Perhaps "elutriation" (which means simply "washing") will become as current technical English as "pH" and other familiar symbols of technical procedure.

Call it what you will, the work on preparation of sludge done at Baltimore under the auspices of Mr. Genter, which has been so ably described in the paper by Messrs. Keefer and Kratz, presents a new and interesting phase of that most important part of sewage treatment—the final handling of the sludge.

With the increasing interest in the dewatering of sludges, whether raw, digested, mixed or otherwise, by means other than the conventional bed drying, it has become more important that the most economical pro-

cedure be employed in order to make these newer methods, particularly the vacuum drying of sludge, fit the smaller plants. It has not been difficult to show that in plants handling the sewage of large populations, the cost of either open or glass-covered sludge beds would be much greater than the cost of vacuum filters, and the saving in some cases has been sufficient to cover the higher operating costs of the vacuum filter.

But in the case of smaller plants it has not been so simple, and the actual economy of vacuum filters could not be shown. In a number of cases they have been adopted for small plants merely to solve the esthetic problem by the elimination of the glass-covered beds, which served to advertise to the world that "there is a sewage plant."

It has been found universally that in order to filter sludge of any kind on a vacuum filter at a practical rate, it was necessary to condition the sludge by the addition of some chemical reagent. Depending on the character of the sludge, this has meant in many cases an expense and a troublesome element to handle. To obtain filter capacities within reason it has been found necessary, generally, to add ferric chloride or other chemicals at the rate of from 6 to 10 per cent or more of the weight of dry solids in the sludge.

With this addition it has been shown possible, commercially, to obtain filter rates on digested sludge of 6 pounds dry weight of sewage solids, per square foot per hour.

Mr. Genter's work at Baltimore, which, fortunately, has been carried on under favorable auspices, with close and accurate analytical control, at a plant where continued runs could be made, has brought forth a principle which promises to put an entirely different light on this subject.

By a relatively simple operation of washing the sludge and concentrating it prior to application to the vacuum filter, he has been able to show conclusively, as indicated by the interesting and carefully prepared charts accompanying the paper, that by this operation filter capacities have been materially increased, and at the same time chemical quantities have been reduced.

This paper brings out additional valuable data in the form of charts showing the results of the use of different chemicals. While ferric chloride produced the best results in the case of the Baltimore sludge, it must not be assumed that the same conditioner will always be the most suitable or economical at another plant. Sludge character, availability of chemicals, extent of local supply, local manufacturing plants producing chemicals, local expediency, etc., all enter into the calculation of the cheapest conditioner for a given job.

For instance, at Providence, R. I., an ample supply of ferric chloride is available at a chemical plant adjacent to the sewage plant, which

makes it possible to deliver ferric chloride at less than 2 cents per pound. Birmingham, Ala., a city surrounded by steel mills, has found it more economical to use chlorinated copperas, on account of an abundant supply of ferrous sulphate at a very low cost, and a low price for delivered chlorine. At another plant, due to some such local condition, ferric sulphate might be the cheapest. Therefore, it is always advisable for experimenters to try a number of conditioners, first evaluating the local sources of supply before making any economic determinations.

On the whole, however, ferric chloride seems to act favorably as a conditioner for practically every sludge, but on account of its highly corrosive nature, it requires filter and other equipment of special construction.

The charts presented by Keefer and Kratz show splendidly the direct comparison of the effect of the several conditioners tried, and the filter rates obtained with them, with or without elutriation. One of the most interesting of the charts is that showing the effect on filter capacity of reducing the amino-ammonia nitrogen, indicating clearly that the principle is correct. Whether this is accomplished through washing out solids in solution, which reduce the ammonia, or whether it is an actual elimination of ammonia in soluble form is unimportant. The effect on the reduction of filter size and increase of filter rate is the important factor.

It is also interesting to note that the greater the elutriation the greater the filter capacity and the less the amount of conditioner required. Keefer and Kratz carried this only to the ratio of 1 part sludge to 3 parts water. As at that dilution the chemical dosage had been reduced to about 2 per cent, it is doubtful if further dilution would have resulted in much further reduction in chemicals, but it would have been interesting to have a figure on a ratio of 1 part sludge to 4 parts water, in order to indicate that the results of their work lie within the practical limits of plant practice.

The carrying out of the elutriation process involves, it is true, the addition of some equipment to handle the washing and sludge concentration prior to the filtration operation, but this would be relatively small, even in a large plant. When it is considered that a square foot of vacuum filter installed will run, with accessories, between $60 and $70, it can readily be seen that doubling filter rates would cut down the filter area to an extent where the saving would go far toward paying for the extra equipment involved.

It will be interesting to have further demonstration of this new phase of sludge treatment on sludges from other plants, and of varying mixtures, properly to evaluate its general usefulness.

EFFECT OF AERATION ON THE RATE OF OXIDATION OF ACTIVATED SLUDGE MIXTURES *

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Most of the papers published in connection with the activated sludge process are concerned with what the process can accomplish under various conditions of operation, with special emphasis on the quality of the end product. It has probably not been sufficiently emphasized that the quality of the end product is mainly a result of the stage of oxidation of the activated sludge. There have been very few attempts to link the different stages of activation and oxidation with the quality of the effluent. It is recognized that the activated sludge process is one of oxidation, but we know little about the minimum, optimum and maximum limits of oxidation and how these in turn affect the quality of the effluent.

The investigations reported here were started in February, 1933, and are concerned with the first part of the problem, namely, evaluation of the extent of oxidation. The correlation of the degree of oxidation with the quality of the effluent will be dealt with subsequently. We have used the two commonly accepted tests for this purpose, suspended solids and B.O.D., not as applied to quality of the effluent but to the sludge itself.

Besides the theoretical value of the proper evaluation of the limits of oxidation the problem has a distinct practical bearing. If we can determine the degree of oxidation of the sludge and subsequently show a relation between this and the quality of the effluent, we can use this information to control the operation.

Method

The procedure consisted mainly of aerating mixtures of activated sludge and sewage for different periods at 20° C. The sewage was obtained from Plainfield and the returned sludge from Tenafly. The amount of air used was sufficient to keep the solids in suspension. At intervals the mixtures were sampled and suspended solids and B.O.D. determinations were made. The B.O.D. was determined in 100 p.p.m. sodium bicarbonate water incubated at 20° C. for 5 days. The results are the averages of 3 dilutions.

* Journal Series Paper, N. J. Agricultural Experiment Station, New Brunswick, N. J., Dept. Water and Sewage Research.

Results

Suspended Solids Reduction.—The results from five series of studies are brought together in Table I. The results are arranged according to increasing concentrations of suspended solids ranging from sewage alone, through increasing concentrations of sludge to 100 per cent. The results are calculated as percentage reduction or increase over the original. A perusal of Table I will show more increases than decreases in the suspended solids content, with the shorter periods of aeration, and vice versa with longer periods of aeration. The percentage increases and decreases are small and yet we believe not without significance.

Table I.—*Reduction or Increase of Suspended Solids in the Aeration of Activated Sludge Mixtures*

	Initial Suspended Solids	Hours Aerated		
		6	24	48
	P.P.M.	%	%	%
Sewage	165	+12.0	− 3.0	−15.0
"	285	+12.3	− 3.5	—
"	285	+12.3	−10.5	−22.8
"	290	+ 1.7	+10.3	− 6.9
"	455	0	− 3.3	—
Mixtures	450	0	− 5.5	−10.0
"	540	+ 3.7	+11.0	—
"	690	+ 0.7	+ 2.9	—
"	690	+ 7.2	+ 2.9	+ 2.2
"	840	+ 1.2	+ 1.8	− 9.0
"	920	0	+ 2.2	− 6.5
"	1,025	+ 1.9	+ 5.8	—
"	1,385	+ 3.6	+ 2.9	+ 1.0
"	1,495	+ 3.7	− 6.0	—
"	1,530	0	+ 2.6	—
"	1,585	+ 5.0	+ 4.4	− 1.2
"	1,675	− 1.5	− 5.7	− 7.2
"	1,990	+ 9.3	+ 9.3	—
"	2,410	+ 1.8	− 4.3	−11.8
"	2,920	+ 1.7	+ 1.9	0
"	3,090	+ 1.8	− 0.7	—
"	3,260	− 2.6	+ 1.5	− 6.6
"	5,390	0	− 5.7	—
"	5,595	+ 0.4	+ 4.0	− 2.0
"	5,690	− 5.5	0	—
Sludge	8,525	− 3.0	− 4.6	−11.1
"	11,940	+ 1.4	+ 2.3	—
"	14,785	− 3.9	− 3.1	—
"	14,900	− 5.5	− 2.1	—

The results are averaged into 5 groups in Table II. In the sewage group with 6 hours aeration there is an average increase of 7.7 per cent in suspended solids, and decreases of 2.0 and 14.9 per cent, respectively, in 24 and 48 hours aeration. The average results for the sludge itself

TABLE II.—*Average Reduction or Increase of Suspended Solids in the Aeration of Activated Sludge Mixtures*

	Initial Suspended Solids	Hours Aerated		
		6	24	48
	P.P.M.	%	%	%
Sewage	165–455	+7.7	−2.0	−14.9
Mixture	450–1,025	+2.1	+3.0	− 5.8
"	1,385–1,990	+3.3	+1.3	− 2.4
"	2,410–5,690	−0.3	−0.5	− 5.1
Sludge	8,525–14,900	−2.7	−1.9	−11.1

do not show increases but a slight percentage decrease during the first 24 hours of aeration. The various mixtures, with the exception of the one with the highest suspended solids concentration, show increases during 6 and 24 hours aeration, but after 48 hours all mixtures show decreases.

B.O.D. Reduction.—The percentage B.O.D. reductions for the same five series of experiments are tabulated in Table III in the order of increasing suspended solids concentration. Unlike the suspended solids figures, only 9 cases out of 29 show increases in B.O.D. in 6 hours of aeration. Generally the percentage B.O.D. reductions are greater than the percentage increases. After 24 hours of aeration there are no increases of B.O.D., although there is considerable variation between the various mixtures in the magnitude of reduction. The individual B.O.D. reductions do not seem to be correlated with the suspended solids concentration of the original mixture. We have arranged these results into 5 groups as shown in Table IV and Figure 1. It will be seen that the average B.O.D. reduction in sewage in 6 hours of aeration was nil but it increased rapidly in 24 hours and maintained the same rate during the second 48 hours aeration. The sewage itself gave the highest percentage of B.O.D. reduction during 48 hours aeration. In the mixture with the lowest amount of sludge the average B.O.D. reduction in 6 and 24 hours was higher than that in sewage without sludge but the 48-hour reduction was lower than that of the sewage alone. With a larger amount of sludge (1,385–1,990 p.p.m.) the average reduction in the first 6 hours of aeration was still higher but after 48 hours the per-

centage reduction was the same as in the mixture with 450–1,025 p.p.m. suspended solids. The mixtures with the largest amount of sludge showed the lowest average reductions in B.O.D. of all the mixtures, both

TABLE III.—*B.O.D. Reduction or Increase in the Aeration of Activated Sludge Mixtures*

	Initial Suspended Solids	Initial B.O.D.	Hours Aerated		
			6	24	48
	P.P.M.	P.P.M.	%	%*	%*
Sewage	165	200	+ 2.5	20.0	47.5
"	285	275	+ 5.4	18.2	—
"	285	360	− 7.0	44.4	64.0
"	290	335	+ 4.5	10.4	44.8
"	455	360	− 7.0	3.0	—
Mixture	450	445	− 2.2	13.5	50.0
"	540	470	− 8.5	16.0	—
"	690	530	−11.5	36.0	—
"	690	480	−16.6	45.5	47.9
"	840	600	+15.0	30.8	49.2
"	920	515	+ 0.9	1.9	23.3
"	1,025	655	−25.2	40.5	—
"	1,385	725	− 3.4	31.0	35.1
"	1,495	790	−26.0	20.3	—
"	1,530	745	−15.3	26.1	—
"	1,585	910	−25.8	27.0	46.1
"	1,675	945	− 7.0	29.1	50.2
"	1,990	805	−34.1	—	—
"	2,410	1,070	+ 9.8	20.6	38.8
"	2,920	1,175	−10.6	20.9	32.8
"	3,090	1,235	−14.1	20.7	—
"	3,260	1,675	−31.3	34.0	51.6
"	5,390	1,925	− 7.1	10.4	—
"	5,595	2,165	−30.7	20.0	36.0
"	5,690	1,950	+ 1.3	10.6	—
Sludge	8,525	2,550	+ 6.0	15.9	38.0
"	11,940	3,180	+ 7.0	16.3	—
"	14,785	4,400	−22.7	0	24.5
"	14,900	3,300	− 5.1	7.0	—

* All reductions.

with short and long periods of aeration. The sludge itself gave the lowest average reduction.

B.O.D. to Suspended Solids Ratio.—Since B.O.D. appears to be correlated with suspended solids, results given in the former tables were recalculated and the B.O.D. expressed on the basis of unit amount of suspended solids. The results, whether expressed as ratio of B.O.D. to

TABLE IV.—*Average B.O.D. Reduction in the Aeration of Activated Sludge Mixtures*

	Initial Suspended Solids	Initial B.O.D.	Hours Aerated		
			6	24	48
	P.P.M.	P.P.M.	% Red.	% Red.	% Red.
Sewage	165–455	200–360	0.3	19.2	52.1
Mixture	450–1,025	445–655	6.9	26.7	42.6
"	1,385–1,990	725–945	18.6	26.7	43.8
"	2,410–5,690	1,070–2,165	11.8	19.6	39.2
Sludge	8,525–14,900	2,550–4,400	3.7	9.8	31.2

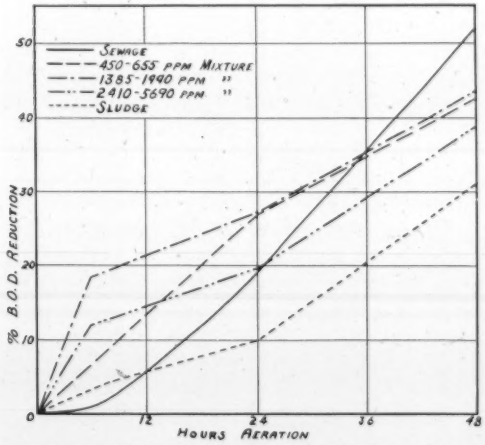

FIG. 1.—B.O.D. reduction in the aeration of activated sludge mixtures.

suspended solids or as parts of B.O.D. required to oxidize 1 part of suspended solids, are a true index of the stage of oxidation of the suspended matter. The higher the ratio or the value, the poorer the stage of oxidation of the material and vice versa. The results are tabulated in Table V. It will be seen that the ratio is wide for sewage and becomes narrower as the amount of returned sludge in the mixture increases. It also is wide prior to aeration and gets narrower as the aeration period is increased. The returned sludge has the narrowest ratio of .22–.30. The results averaged into 5 groups are given in Table VI, which show the same relationship in a more uniform way.

TABLE V.—*B.O.D.-Suspended Solids Ratio in Activated Sludge Mixtures*

	Initial Suspended Solids	Hours Aerated			
		0	6	24	48
	P.P.M.	%	%	%	%
Sewage	165	1.2	1.1	1.0	.75
"	285	.95	.90	.82	—
"	285	1.26	1.05	.78	.59
"	290	1.15	1.19	.94	.68
"	455	.80	.73	.80	—
Mixture	450	.99	.97	.90	.55
"	540	.87	.77	.66	—
"	690	.77	.68	.48	—
"	690	.69	.54	.46	.35
"	840	.71	.81	.48	.40
"	920	.56	.56	.54	.46
"	1,025	.64	.47	.36	—
"	1,385	.52	.49	.35	.33
"	1,495	.53	.38	.45	—
"	1,530	.49	.41	.35	—
"	1,585	.57	.40	.40	.31
"	1,675	.56	.50	.42	.30
"	1,990	.40	.24	—	—
"	2,410	.44	.48	.37	.31
"	2,920	.40	.35	.31	.27
"	3,090	.46	.33	.32	—
"	3,260	.51	.36	.33	.27
"	5,390	.36	.29	.27	—
"	5,595	.39	.27	.30	.25
"	5,690	.34	.37	.24	—
Sludge	8,525	.30	.33	.26	.21
"	11,940	.27	.28	.30	—
"	14,785	.30	.24	.30	—
"	14,900	.22	.22	.21	—

TABLE VI.—*Average B.O.D.-Suspended Solids Ratio in Activated Sludge Mixtures*

	Initial Suspended Solids	Hours Aerated			
		0	6	24	48
	P.P.M.	%	%	%	%
Sewage	165–455	1.07	.95	.87	.67
Mixture	450–1,025	.75	.69	.55	.44
"	1,385–1,990	.51	.40	.39	.31
"	2,410–5,690	.41	.35	.31	.27
Sludge	8,525–14,900	.27	.27	.27	.21

TABLE VII.—*Changes in Oxygen Consumed Value of Activated Sludge Mixtures With Aeration*

	Suspended Solids				Oxygen Consumed				Oxygen Consumed / Suspended Solids			
	Hours Aerated											
	0	7	24	48	0	7	24	48	0	7	24	48
	P.P.M.	P.P.M.	P.P.M.	P.P.M.	P.P.M.	P.P.M.	P.P.M.	P.P.M.	%	%	%	%
1. Sewage	285	320	255	220	305	250	260	190	1.07	.80	1.00	.86
2. Mixture	840	850	855	765	730	355	370	365	.87	.42	.43	.48
3. "	1675	1650	1580	1555	940	685	660	645	.56	.41	.42	.41
4. "	2410	2455	2305	2125	1400	905	930	880	.58	.37	.40	.41
5. Sludge	8525	8265	8130	7575	3775	3140	2760	2760	.44	.38	.34	.36

Permanganate Oxygen Consumed of Activated Sludge Mixtures.—It would seem possible to measure the oxidation by the oxygen consumed test as well as the B.O.D. The former determination could be made quickly and therefore might be of more value than B.O.D. for process control. We therefore made a study of the significance of the oxygen consumed test. The results of one series are presented in Table VII. Oxygen consumed values decrease with increasing periods of aeration. The ratio of oxygen consumed to suspended solids gives a value for sewage alone which tends to diminish with increasing amounts of sludge and also tends to diminish with increasing periods of aeration.

Changes in the Percentage Ash of Suspended Solids.—Does oxidation in the activated sludge process result in a relative increase in the ash content of the suspended matter and if so can this test be used in determining the stage of oxidation? Given a sewage of domestic origin or working with a sewage of more or less constant quality, the higher the ash content of the resulting activated sludge, the higher would be the stage of oxidation. The results in Table VIII show this assumption to

TABLE VIII.—*Changes in the Percentage Ash of the Suspended Solids in Activated Sludge Mixtures*

	Initial Suspended Solids	Ash in Suspended Solids			
		Hours Aerated			
		0	7	24	48
	P.P.M.	%	%	%	%
1. Sewage	285	16.5	15.9	18.4	18.2
2. Mixture	450	19.3	17.8	19.7	19.8
3. "	840	23.4	21.9	23.8	24.3
4. "	1675	25.4	26.2	28.2	27.9
5. "	2410	26.7	28.0	29.0	27.8
6. Sludge	8525	34.2	34.2	35.4	36.0

be true. The suspended solids of sewage alone have a low percentage ash content. After 7 hours of aeration there is a slight decrease in the ash content and a subsequent increase in 24 hours. In the mixtures containing sludge the ash content is relatively high and does not undergo much change with aeration. With increasing concentrations of suspended solids the initial ash content increases. The two lower concentrations of suspended solids indicate a slight dip in the percentage ash after 7 hours of aeration, similar to the sewage, but the higher concentrations do not show this tendency. In all of the mixtures the ash con-

tent tends to increase after 7 hours of aeration, but in no instance does it attain the high value of sludge alone, even after 48 hours of aeration.

Discussion

The suspended solids results must be interpreted carefully and critically since the differences are small and not uniform. However, in spite of these difficulties, some clear cut tendencies are apparent. In the first place it appears that the reduction of suspended matter due to oxidation is small. There may even be an increase in suspended matter with shorter periods of aeration. The increases in 6 hours of aeration are more frequent and are of higher magnitude with the low suspended solids concentrations than in 24 hours and high suspended solids concentration. This would tend to show that the increases are due to the colloidal matter flocculating as a result of aeration and being determined as suspended solids. Flocculation, therefore, takes place even in the absence of activated sludge. It results in the transference of solids from a non-settleable state, in the sewage, to the settleable state of the activated sludge. This in turn results in the building up of the solids. However, the observed figures are the resultant of two tendencies working simultaneously in opposite directions, the first the accumulation of solids due to flocculation and the second the oxidation of the solids.

The dip in the percentage ash of the suspended solids with short periods of aeration would support the above view. As the sewage solids with low ash content are transferred to the sludge the tendency would be to lower the ash content until the opposite tendency of increasing ash content due to oxidation overtakes it.

The picture is entirely different with the B.O.D. figures. We have here rather consistent and significant reductions of B.O.D. with even short periods of aeration. There are a few increases in B.O.D. noted with the shorter period of aeration and the individual reductions are not so uniform. However, the results averaged into groups according to the suspended solids concentrations show definite tendencies. The first significant fact is that the reduction of B.O.D. of sewage in the absence of activated sludge is low in the first 6 hours of aeration. This initial lag period of oxidation of sewage, in the absence of sludge, is decreased with increasing amounts of sludge up to a certain concentration. Beyond this, the addition of more sludge results in a lower percentage decrease of B.O.D. It is apparent, therefore, that there is an optimum ratio of non-oxidized sewage solids and partially oxidized activated sludge solids which gives a maximum B.O.D. reduction. When this ratio is exceeded and the already oxidized sludge solids predominate the percentage reduction of B.O.D. will not be great. On the other hand, the presence of small amounts of sludge stimulates the B.O.D. reduction of

the sewage solids during the shorter periods of aeration commonly in practice. With longer periods of aeration the oxidation of sewage proceeds rapidly even in the absence of activated sludge and attains a higher value than any of the mixtures. That with a proper amount of returned sludge the oxidation as measured by B.O.D. reduction may be as high as 20 per cent in 6 hours indicates that oxidation is an important and integral part of the activated sludge process and may in turn affect the degree of clarification and purification.

The method of expressing the B.O.D. results on the basis of unit amount of suspended solids gives valuable information in regard to the stage of oxidation of the solids. If a mixture is poorly oxidized it will have a relatively high B.O.D. value on the basis of unit amount of solids. This is substantiated by the results in Table V. The B.O.D.-suspended solids ratio is wider for sewage than for the mixtures and is wider for mixtures with lower suspended solids concentration than those with higher concentrations. Furthermore, the ratio decreases for a given concentration with increasing periods of aeration. Sludge alone gives values varying between .22–.30 with an average of .27. The mixtures with low suspended solids concentration require a long time to reach this ratio and as the suspended solids concentration is increased the time required to reach the ratio is decreased. Thus for diagnostic purposes the B.O.D. suspended solids ratio is a valuable index of the stage of oxidation of the sludge. Attempts to correlate these ratios with the performance and efficiency of the sludge in regard to purification will be presented later.

It would be more practical if the stage of oxidation of the sludge could be determined in a shorter period than is required for the B.O.D. determination. The results with oxygen consumed test indicate good possibilities in this respect.

Summary

Working under laboratory conditions with the aeration of various proportions of activated sludge and sewage, the following results are demonstrated:

1. The reduction of suspended solids is low and there may even be an initial increase due to the transference of colloidal matter in sewage to the activated sludge.

2. Simultaneously with the increase in suspended solids there is a decrease in the percentage ash of the suspended solids, due to the low ash content of sewage solids as compared with activated sludge. The percentage ash increases with aeration after this initial decrease.

3. The B.O.D. reduction with short periods of aeration is definitely influenced by the proportion of activated sludge, up to a certain point.

The sewage itself shows very low B.O.D. reduction in 6 hours but as the suspended solids concentration is increased the reduction is increased. Beyond a certain point, however, the increase in suspended solids concentration results in lower percentage reduction, since the reduction in the sludge itself is low. The reduction attained after 48 hours of aeration is higher with sewage than with mixtures of sewage and sludge.

4. The B.O.D.-suspended solids ratio of sewage is high (around 1.0) and of activated sludge is low (.22–.30), and in the various mixtures the ratio varies inversely with suspended solids concentration. The ratio becomes narrower as a result of aeration and if the aeration period is long enough or the suspended solids concentration high enough it attains the value of the returned sludge itself.

INVESTIGATION OF RAPID METHODS FOR SLUDGE SOLIDS ESTIMATION

By J. I. Smith

Chemist, Calumet Sewage Treatment Works, The Sanitary District of Chicago

In the operation of an activated sludge plant it is important to obtain frequent checks on the amount of solids in the aeration tanks and the return sludge. Also, the control of activated sludge filtration on a plant scale requires a knowledge of the solids in the wet sludge before it can be properly conditioned with ferric chloride. A rapid and reliable test for sludge solids is therefore of practical value.

The standard method, which has been the usual procedure in our laboratory, for determining the solids in sludge is as follows: a 100 gram sample of sludge is placed in a weighed 125 c.c. porcelain evaporating dish and dried in an oven at 105° C., after which it is cooled and weighed. The drying requires about eight hours or, for convenience, over night. The dried sample is weighed the next morning. The results of the test are therefore not available the same day the sample is received.

This delay has resulted in the investigation of various rapid methods for the estimation of sludge solids. The following have been investigated in this laboratory during the past year: (1) centrifuging the sludge, (2) determining the specific gravity by weight, (3) weighing the solids which have been filtered and dried in a special aluminum dish.

The Centrifuge Method

Three sizes of graduated centrifuge tubes were available for our tests: 100 c.c., 50 c.c., and 15 c.c. The 100 and 50 c.c. tubes were not graduated closely enough for practical use. Therefore, the tests were run with 15 c.c. tubes (see Fig. 1) which were graduated to 0.1 c.c. divisions. The procedure was as follows: Two tubes, each with 15 c.c. duplicate samples of sludge, were centrifuged in a closed motor-driven centrifuge for three minutes after uniform speed had been reached. This speed was about 2,200 r.p.m. and it was reached in approximately one-half minute. At the end of three minutes the centrifuge was allowed to come to a stop gradually, the tubes were removed immediately and the cubic centimeters of deposited sludge noted. Some of the re-

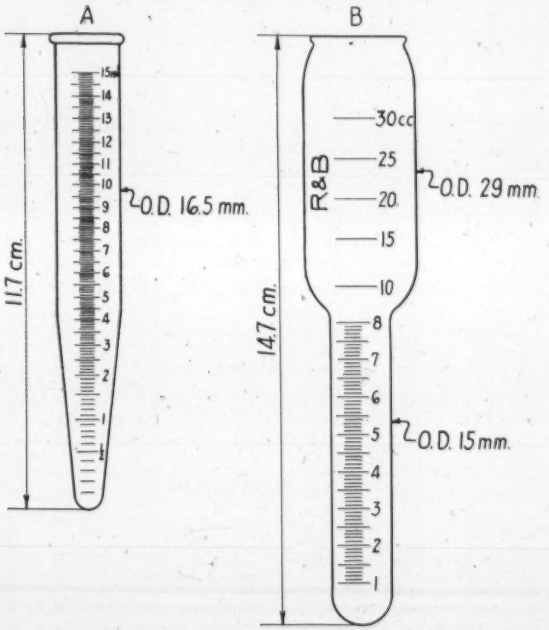

FIG. 1.—Glass tubes used in centrifuge tests. "A", 15 c.c. tube used in this investigation, "B", 30 c.c. tube of modified design.

sults of these tests are tabulated in Table I and graphically represented in Fig. 2.

A study of the data indicates that in many cases the results were somewhat unreliable. The following examples show the degree of variation: 1.05 per cent solids gave readings from 1.4 to 1.8 c.c.; 1.43 per cent solids gave readings from 2.3 to 2.75; 1.7 per cent solids gave readings from 2.7 to 3.2. Duplicate tests on the same sample often gave readings which varied 0.2 c.c. The variation in the speed of the centrifuge, probably due to fluctuation in current supply, is one of the causes of error. To verify this, the speed of the centrifuge was deliberately changed by means of the rheostat setting, the r.p.m. being checked by the use of a speed indicator. The results showed that an increase or decrease of approximately 130 r.p.m., from 2,000 r.p.m., caused from 0.1

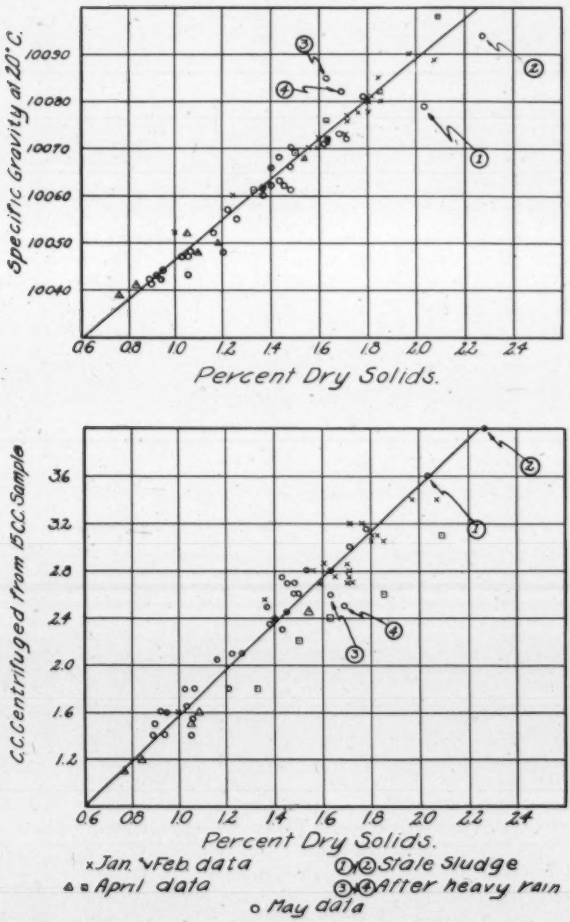

FIG. 2.—Graphs showing relation between specific gravity and solids (above) and between volume of centrifuged sludge and solids (below).

to 0.2 c.c. difference in the sludge readings. However, the main cause of variation is the non-uniformity in the character of the sludge particles. One evidence of this is after a heavy rainfall when the sewage solids contain relatively more mineral matter. As an example take June 26 (Fig. 2) when 1.69 per cent sludge gave a centrifuge reading of 2.5, whereas the normal reading for sludge of this concentration is about 2.9. For the three days prior to this date the total rainfall was 1.35 inches. The volatile matter in this sample was 54 per cent, whereas the average for the month was about 61 per cent. Although this variation appeared to be due to a decrease in volatile matter, a study of the data does not reveal any uniform relationship between the volatile matter and the centrifuged solids.

In general, the centrifuge test is probably satisfactory enough for rough plant control work, but as a matter of record should be supplemented by actual solids determination. In the hope of increasing the accuracy of the test the writer has designed a special centrifuge tube (Fig. 1). The tube will hold 30 c.c. and the lower half, of small diameter, is graduated in 0.1 c.c. divisions. It will fit in the standard carrier for 50 c.c. tubes. As yet only a few tests have been run with these new tubes, but indications are that the results will be much more satisfactory than those obtained with the smaller 15 c.c. tube. The new tube will take a larger sample, and the centrifuged sludge can be read more accurately than in the 15 c.c. tube.

The Specific Gravity Method

The torsion gravity balance has been used successfully in the laboratory for several years for determining the specific gravity of sludge. This balance weighs accurately to four decimal places and is equipped with a ground-glass stoppered bottle calibrated for 100 c.c. at 20° C. It is necessary to heat or cool the sludge to exactly 20° C., or use a correction factor for temperature difference. The use of temperature correction factors did not prove very satisfactory, so the following rapid method for bringing the sludge to the proper temperature was used. The sludge was poured into a wide mouth eight-ounce bottle fitted with a rubber stopper and thermometer. If the sludge was colder than 20°, as in winter, the bottle was held under a stream of hot water, shaking continuously and looking at the thermometer about every 10 seconds until the temperature reached exactly 20° C. It was then immediately put in the gravity bottle and weighed. The whole procedure required only from five to seven minutes and no correction factors were necessary. In summer the sludge must be cooled to 20° in the same way, using cold water.

The results of a number of specific gravity and solids tests are tabu-

TABLE I.—*Data for Comparison of Specific Gravity and Centrifuge Methods*
Source of Samples: Activated sludge wasted from final settling tank

Date 1934	Per Cent Solids	Per Cent Volatile	Specific Gravity 20° C.	Centrifuge Readings, c.c. 15 c.c. Sample
Jan. 19	1.56	64.0	1.0070	2.8
19	1.24	—	1.0060	2.1
19	1.00	—	1.0052	1.6
22	1.76	64.2	1.0078	3.2
22	1.80	62.7	1.0078	3.05
23	1.80	62.9	1.0080	3.1
24	2.07	64.6	1.0089	3.4
24	1.71	63.3	1.0073	2.75
25	1.82	64.3	1.0085	3.1
25	1.72	64.7	1.0077	2.7
26	1.70	64.2	1.0067	2.85
26	1.63	62.0	1.0072	2.6
27	1.97	62.5	1.0090	3.4
29	1.81	61.3	1.0081	3.1
30	1.71	63.5	1.0077	3.2
Feb. 2	1.63	65.9	1.0071	2.75
2	1.71	66.7	1.0076	2.8
3	1.59	63.7	1.0070	2.7
6	1.71	65.5	1.0076	2.8
7	1.60	60.8	1.0072	2.85
8	1.85	63.3	1.0080	3.05
9	1.70	65.7	1.0073	2.7
Max.	2.07	66.7		
Min.	1.00	60.8		
Ave.	1.67	63.6		
Apr. 18	0.84	60.1	1.0041	1.2
19	1.05	60.0	1.0052	1.5
20	2.09	60.0	1.0098	3.1
20	*1.85	—	1.0082	2.6
20	*1.63	—	1.0076	2.4
20	*1.50	—	1.0069	2.2
20	*1.33	—	1.0061	1.8
21	0.77	60.8	1.0039	1.1
27	1.09	58.8	1.0048	—
28	1.54	62.8	1.0068	2.45
30	1.18	60.8	1.0050	1.6
Max.	2.09	62.8		
Min.	0.77	58.8		
Ave.	1.35	60.5		

* Diluted from preceding sludge sample by the addition of supernatant sludge liquor.

TABLE I.—*Continued*

Date 1934	Per Cent Solids	Per Cent Volatile	Specific Gravity 20° C.	Centrifuge Readings, c.c. 15 c.c. Sample
May 1	1.21	59.2	—	1.8
2	1.05	60.0	1.0047	1.55
3	1.03	—	1.0047	1.65
3	1.43	58.2	1.0068	2.75
4	1.05	66.7	1.0043	1.4
5	1.02	65.9	1.0048	1.7
8	1.22	64.0	1.0057	2.1
8	1.43	64.0	1.0063	2.3
9	1.26	63.0	1.0055	2.1
9	1.48	—	1.0061	2.6
10	0.89	61.9	1.0042	1.5
10	1.37	63.0	1.0060	2.5
11	1.40	62.5	1.0062	2.4
11	1.49	62.8	1.0067	2.7
12	0.95	59.7	1.0044	1.6
12	1.06	61.8	1.0048	1.8
14	1.38	63.5	1.0061	2.35
14	0.90	63.2	1.0041	1.5
15	0.94	62.7	1.0042	1.4
16	1.71	64.2	1.0072	3.0
16	1.68	63.5	1.0073	2.85
18	1.45	65.1	1.0062	2.45
18	†2.27	64.3	1.0094	4.0
19	1.53	64.8	1.0068	2.8
19	1.63	62.5	1.0072	2.8
22	1.16	59.9	1.0052	2.1
24	1.40	61.0	1.0066	2.4
25	1.78	59.7	1.0081	3.15
25	0.92	59.3	1.0043	1.6
26	1.48	61.0	1.0070	2.6
26	1.71	60.9	1.0076	3.0
28	1.45	63.9	—	2.7
28	†2.03	64.2	1.0079	3.6
29	1.48	64.2	1.0066	2.7
31	1.63	65.0	—	2.5
Max.	2.27	66.7		
Min.	0.89	58.2		
Ave.	1.36	62.4		
June 26	‡1.63	53.2	1.0085	2.6
26	‡1.69	54.0	1.0082	2.5

† Stale sludge.

‡ Very heavy rainfall 22nd to 25th, total: 1.35 in.

lated in Table I and shown graphically in Fig. 2. A study of the records over a number of years shows that seasonal changes, due to weather conditions, definitely affect the relationship between the gravity and the per cent dry solids. As an example take the extreme case of June 26 which was preceded by a rainfall of 1.35 inches. The sludge, 1.63 per cent solids, had a specific gravity of 1.0085 as compared with a normal gravity of about 1.0073 for this sludge. However, the relationship from day to day is constant enough, except in extreme cases, to estimate the solids within plus or minus 0.1 per cent, which is precise enough to make it practical as a control test. The following cases are sufficient to show the variable range of the method. Sludge of 1.05 per cent solids had gravities from 1.0043 to 1.005; 1.48 per cent sludge from 1.0061 to 1.0070; and 1.69 per cent sludge from 1.0073 to 1.0082.

A study of the data indicates that the specific gravity test is much more accurate than the centrifuge test. However, because of the delicacy of the gravity balance and the careful technique required, the method can be recommended for use only by a trained chemist in the laboratory. A change of 1° C. in the sludge before it is put in the gravity bottle makes a difference of 0.0002 or 0.0003 in the determination. The presence of a small air bubble, about the size of a pin head, trapped under the stopper is another source of error which will also cause a difference of about 0.0002 in the gravity. Reference to the graph will show that a difference of 0.1 per cent in solids corresponds to a difference of about 0.0004 in specific gravity. Therefore, the importance of careful observance of all precautions is obvious.

A comparison of the two graphs (Fig. 2) gives further evidence that the specific gravity test is more accurate than the centrifuge test. The points on the two graphs, with one or two exceptions, are from the same sludge samples. A much wider divergence of the points from the line will be noticed in the centrifuge-solids graph than in the gravity-solids graph. The points designated by squares represent sludges which were dilutions of a common sludge sample. First, the sludge was concentrated for one hour and the supernatant liquor siphoned off. Then a series of samples was made up by adding varying amounts of sludge liquor. The interesting feature of this series, which is represented by squares in both graphs, is that these points are all quite a distance below the line in the centrifuge-solids graph, whereas in the gravity-solids graph they are all rather near the line, some below and some above. This seems to indicate that the gravity method is more reliable in case the character of the sludge is changed by some outside influence.

Points numbered 1 and 2 are samples of stale sludge which remained in the final Dorr tank about 24 hours due to the failure of the return sludge line. As might be expected, due to gasification, the gravities

were much lower than normal. However, the centrifuge readings were very near the normal. Points 3 and 4 on the graph show the effect of the heavy rainfall, which has been mentioned previously.

The Aluminum Dish Method

This method has been used about a year in the Calumet Laboratory for the determination of suspended solids in the aeration tank mixture in connection with the settling test in liter cylinders. The test was first devised by A. J. Beck in connection with special sludge work at the North Side Sewage Treatment Works. It consists of filtering the sludge by vacuum through filter paper in a flat-bottom aluminum dish with a perforated bottom. The dish and residue are dried for 30 minutes in a 105° C. oven. At the North Side Plant a dish 75 mm. (3 inches) in diameter is used and the vacuum applied by placing the dish on a rubber ring or gasket inside a 100 mm. Buchner funnel. This arrangement is very convenient since the Buchner funnel is standard equipment of almost every laboratory.

In the development of the method at the Calumet Laboratory we use a dish 100 mm. in diameter, 26 mm. deep, with the bottom perforated similar to a Buchner funnel. The filter paper used is Whatman's Number 1, 98 mm. in diameter. Two special holders were devised for applying the vacuum. One was a brass funnel which was fitted to a 250 c.c. graduated cylinder by means of a rubber stopper, the vacuum being applied to the cylinder through a hole in the stopper. This arrangement allows for the inspection and timing of the filtrate if desired. The other holder, which we found most convenient for routine work, was a brass cylinder 4 inches in diameter and 7 inches high. Brass rods supported the dish, and a section of auto tire innertube was used as a vacuum seal. In the cylinder the vacuum was applied through the side by means of a stop-cock. The apparatus is shown in detail in Fig. 3.

The procedure of the test on aeration tank solids is as follows: Dry the dish with filter paper in the 105° C. oven. Cool in a desiccator 10 minutes and weigh. Wet the filter paper, place the dish with paper in the holder and apply about 20 mm. of vacuum. Immediately add 100 c.c. of the sample to the dish and after the water has been extracted dry in an oven at 105° C. for 30 minutes, or at 120° C. for 10 minutes. Remove the dried sample to a desiccator, cool and weigh. The results are expressed as parts per million or per cent of suspended solids.

In order to speed up the test the minimum drying time was determined for several temperatures. At 105° C. it was found to be 30 minutes. Only about 0.4 per cent additional loss in the sludge weight occurred during a second 30-minute drying period. At 110° C. the

minimum time required was about 25 minutes. At 120° C. a period of 10 minutes was sufficient, and at 130° C. the drying was complete in about 8 minutes. However, at 130° C. there is more danger of losing an appreciable amount of volatile matter if the sample is allowed to remain in the oven too long, and the time of drying is not much less

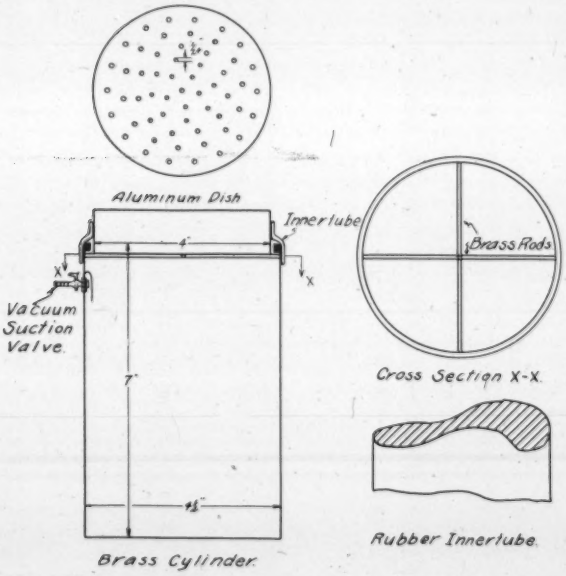

FIG. 3.—Apparatus used for rapid determination of solids, using aluminum dish.

than at 120° C. Therefore, at 120° C. temperature at 10 minutes was selected as being the most practical. An additional 10 minutes in the oven at this temperature showed a loss of only 0.9 per cent of the total dry sludge weight, or 20 in 2210 p.p.m. Table II gives complete data for the aluminum dish method.

The advantages of this method over the conventional Gooch crucible test for suspended solids are as follows: (1) the size of the sample—100 c.c. against 10 or 20 c.c. with the largest size (35 c.c.) Gooch; (2) speed of drying—at 105° C., 30 minutes are required against 60 to 90 minutes for the Gooch, depending on the amount of sample used; (3)

TABLE II.—*Data for Aluminum Dish Method*

Aeration Tank, Susp. Solids, P.P.M.					Return Sludge, Per Cent Solids			Return Sludge, Per Cent Solids		
Aluminum dish used for all samples					Porcelain Dish	Aluminum Dish		Aluminum dish used on all samples		
105° C.	Minutes in Oven	120° C.	Minutes in Oven	Difference	105° C. Overnight	120° C. 10 min.	Difference	105° C. 30 min.	120° C. 10 min.	Difference
(Duplicate samples)					(Duplicate samples)			(Duplicate samples)		
2280*	30	2210*	10	−70	1.60	1.62	+.02	1.68	1.62	−.05
2270*	60	2190*	20	−80	1.19	1.25	+.06	1.62	1.64	+.02
2200	30	2080	20	−20	0.925	0.93	+.005	1.35	1.41	+.06
2370	30	2420	10	+50	1.27	1.22	−.05	1.37	1.36	−.01
2200	30	2230	10	+30	0.88	0.86	−.02	1.61	1.63	+.02
2800	30	2750	10	−50	1.10	1.04	−.06	1.14	1.15	+.01
2280	30	2300	10	+20	1.64	1.64	.00			
2310	30	2250	10	−60	1.38	1.41	+.03			
					1.42	1.36	−.06			

* These are from same sludge sample.

accuracy of the test—duplicates using the aluminum dish method check within 20 to 50 p.p.m. in 2000 p.p.m. Duplicates with the Gooch check only within 100 to 300 p.p.m., due mainly to the small sample. The rapidity of drying in the aluminum dish is due primarily to the fact that the sludge is spread over the surface of the paper in such a thin layer, and the paper is not hygroscopic enough to affect the accuracy seriously. We have made valuable use of the test in this laboratory in conjunction with the 30-minute liter settling test. The 10 minute drying and 10 minute cooling make it possible to weigh the suspended solids during the 30-minute settling period. Thus, the sludge index may be computed and made available immediately.

Another important use we have made of the aluminum dish method is in the determination of the solids in the return sludge from the Dorr settling tank. As already pointed out the evaporation in a porcelain dish takes too long to be of much practical value from an operation standpoint. The procedure with the return sludge is the same as with the aeration tank mixture of sludge and sewage, except that a 50 gram sample is used. In sampling a 50 c.c. pipette was calibrated to deliver 50 grams of wet sludge. The results with this more concentrated sludge show that at 105° C., 30 minutes drying is sufficient and at 120°, 10 minutes. A determination by this method does not include the dissolved solids, which are included in the evaporation method in a porcelain dish. The exclusion of the dissolved solids by the aluminum dish method may rightfully be considered as an additional point in its favor since in the treatment of sludge we are interested primarily in sludge solids as such, not dissolved solids.

In the disposal of waste activated sludge by continuous mechanical filtration, the aluminum dish method for sludge solids estimation has a valuable application, since the amount of conditioner required varies with the sludge solids. Drying the sample at 120° for 10 minutes, cooling for 10 minutes in a desiccator and then weighing allows a report to be made on the test within 30 minutes after receiving the sample. This is rapid enough for practical use as a control test. The time may be shortened about 5 minutes if the dish is cooled by placing it over the vacuum for 5 minutes in the filtration apparatus, and weighing immediately. However, cooling too long in the air must be guarded against, because the absorption of moisture by the sludge and paper will make an appreciable error in the weighing, especially if the humidity is high.

As a result of these studies we have successfully used the aluminum dish method for some months in the control of an activated sludge unit at the Calumet plant; both for determining the per cent solids in the return sludge and the suspended solids in the aeration tanks. We

prefer it to either the specific gravity or centrifuge methods, because it involves direct weighing of the solids, whereas both the gravity and centrifuge tests are indirect methods which are affected by changes in the characteristics of the sludge. However, we frequently use the specific gravity test as an index for solids when speed is essential.

Summary

Three methods for the rapid estimation of sludge solids have been discussed: (1) The centrifuge method, which is useful as a rough control test and requires about 5 minutes for completion; (2) the specific gravity method, which is more accurate than the above, requires from 5 to 7 minutes and more technical skill in manipulation; (3) the aluminum dish method, which involves vacuum filtration, drying, and weighing the solids direct, and is the most accurate of the three under all conditions.

Both the centrifuge and gravity methods are affected by changes in the characteristics of the sludge, such as after a heavy rainfall, whereas the aluminum dish method is accurate under any conditions.

Acknowledgment

The writer wishes to acknowledge the cooperation of Dr. F. W. Mohlman, Director of Laboratories of the Sanitary District of Chicago, for suggestions regarding the preparation of this paper, of A. J. Beck, Principal Sanitary Chemist, for his advice on the aluminum dish method, and of Rascher and Betzold, 829 Orleans Street, Chicago, for their assistance in the design of the special centrifuge tube.

PRESENT STATUS OF CHEMICALS IN SEWAGE TREATMENT *

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This paper is intended to set forth the practical application of chemicals to give satisfactory purification of sewage, and necessarily includes some of the theoretical aspects in order to give a clearer understanding of the results which have been obtained and to partially anticipate what may be expected in the early future.

Knowledge of the fundamental characteristics of the sewage to be treated is of primary importance for an intelligent attack of any particular problem. These characteristics are, in many cases, quite variable; so that in order to obtain uniform results there must be one of two things: EITHER

(*a*) Flexibility of treatment, which is probably best obtained by chemical methods.

OR

(*b*) A plant designed and operated to provide a satisfactory degree of treatment for all cases, including abnormal ones, which is decidedly expensive.

Domestic sewage, as it reaches the average treatment plant, after travelling through a long sewer line, usually has the following characteristic: IMPURITIES.

1. Insoluble solids such as grit, paper, garbage, organic residues, rags, etc.

2. Materials in colloidal suspension or solution largely due to part decomposition by oxidation and bacterial effect before reaching the plant, such as greases, proteins, starches, cellulose compounds, and products formed from decaying vegetable matter, etc.

3. Materials in true solution by virtue of being truly soluble compounds such as alcohols, sugars, organic acids, salts, etc.

I. The insoluble solids can be comparatively easily removed by screening and sedimentation. For fresh average domestic sewage, that is, a sewage received in the plant in less than four hours after its origin, the insoluble material is probably responsible for 50–60 per cent of the 5-day B.O.D. value and 85–90 per cent of the suspended solids, although

* Presented at the Spring Meeting of the New York State Sewage Works Association, Jamestown, June 15–16, 1934.

only 33 per cent B.O.D. and 50 per cent suspended solids removal is the recognized average for sedimentation plants.

II. The material in colloidal suspension or colloidal solution is somewhat more difficult to remove but is probably responsible for 20–25 per cent of the 5-day B.O.D. and 10–15 per cent of suspended solids. Three methods of removal are practical: bacterial oxidation, coagulation with sedimentation, and filtration, or more recently a combination of the two latter methods. A study of the characteristics of these sewage colloids reveals an interesting story.

All colloids, *suspended* in a liquid medium of which water is the principal substance present, carry an excess of positive or negative charge similar to static electrical charges in behavior. In almost neutral solutions most protein colloids carry an excess negative charge which may at lower alkalinities (pH = 4.0) change to neutral and finally become positive with respect to the electrolyte status.

Various colloids have different "neutral points," that is, different alkalinities at which the colloid changes over from positive to negative. Positive colloids usually combine (coagulate) with negative colloids producing a neutrally charged aggregate (floc) which precipitates. $Fe(OH)_3$, $Al(OH)_3$, and $Cr(OH)_3$ are positively charged inorganic colloids, the addition of which influences the formation of such combinations and aggregates, and, under proper conditions, produce heavy aggregates (flocs) which settle readily. For optimum conditions in all cases iron flocs settle most readily, with chromium flocs a close second and with aluminum flocs a rather poor third. Lime alone is used in some cases as a coagulant and its action depends on the actual formation of organic salts and on raising the alkalinity to effect a change in charge on some of the colloids, so they may react with other colloids to give a neutral and precipitated aggregate as above. Starches suspended in neutral solution usually carry an excess of positive charge.

A recent and very interesting theory advanced in the activated sludge process attempts to explain a large part of the clarification and purification as coagulation and sedimentation of insoluble and colloidal compounds. The theory is based on coagulation of negative sewage colloids with positive or less negative sludge particles formed by bacterial oxidation of sewage solids. This has been separately indicated by cataphoretic experiments involving measurement of direction and rate of travel through an electrolyte containing two electrical poles between which a potential difference is maintained. It is entirely probable that a similar precipitation takes place on sprinkling filters but the writer does not know of any specific data which would confirm this.

This effect can be accomplished chemically with greater precision and better control and thus obviate returning sludge which may or may not be properly activated. If this job is to be done chemically the problem is decidedly simplified if the organic matter is kept in comparatively fresh state. This results in having a few insoluble compounds rather than many or more soluble or semi-soluble compounds resulting from decomposition of the originals. The mechanism of chemical coagulation and precipitation consists of adding positive particles such as ferric hydrate, aluminum hydrate, chromium hydrate, fine carbon particles, etc., which form a nucleus toward which negative colloids are attracted. The activity and energy characteristics, which are responsible for solubilities and solution properties, are changed when a union of the two oppositely charged colloids occurs. As the activity and energy characteristics are definitely influenced by the alkalinity of the liquid medium, very close pH control is usually necessary to produce efficient results. When proper conditions can be maintained some of the completely soluble compounds will be precipitated along with the colloids and insoluble materials and will give a higher degree of purification than can be had by haphazard addition of chemicals which tend to produce coagulation and sedimentation. The salts and various soluble compounds all have a definite influence on the energy and reactivity of the materials in any system, so that industrial wastes, dilutions and local conditions make for individual problems for many plants. The same characteristics influence biological plants and have a very similar effect on plant performance and degree of purification.

As a matter of fact the chemical aspects of biological and chemical treatments seem much the same, and we are just learning that many of the variations in results from biological plants can best be treated chemically, such as pH adjustment and aiding sedimentation of bulking sludge. From a chemical standpoint, biological treatment merely changes the chemical and physical properties of the compounds present so that they will coagulate and precipitate. The two practical differences in the results obtained to date are first, that chemical treatment, due to our present limited basic knowledge of control of the reactions, does not remove quite as much of the soluble substances present, while a well designed chemical plant, including filtration, will remove more of the insolubles, and second, that a biological plant, whether designed for a high degree of treatment or not, yields a sludge which to date has proven a decided nuisance when compared with sludge from a chemical plant.

Concerning the use of ferrous iron as such, it is absolutely certain that we can have no coagulating effect until the Fe^{++} (ferrous iron) is oxidized

to Fe^{+++} (ferric), which is possible in sewage only at alkalinities above pH 7.2, practical oxidation efficiency limits pH to 7.8 or higher. The reason for this is that the extra positive charge on the ferric iron is the active element involved. It was found at Dearborn that iron wastes in the raw sewage were practically ineffective at alkalinities pH 6.5–7.5, and resulted in almost the same concentrations of iron in the effluent as found in the raw.

III. Soluble material, although partly removed with lime and iron salts, can probably be better removed with activated carbon. Activated carbon has most of the properties of a positive colloid and has a quite selective absorption of specific compounds. The ammonia and amino compounds can be liberated with alkali and some of them be removed by aeration, or chlorinated to give decidedly more stable compounds. Guggenheim has worked out a zeolite filter for removing soluble nitrogenous compounds. Catalyzed air oxidations effect a good removal of soluble impurities by converting them to CO_2, H_2O and NO_3 but if insoluble impurities are present some of them are partially liquefied and thereby made soluble so that the net result is only 25–50 per cent removal of the soluble organic material.

Flocculation.—The contact of neutral aggregates by mechanical or air agitation effects an accumulation of several particles to form one larger particle with consequent squeezing out of water, due to cohesive and adhesive properties of the solids. As the particles grow larger and lose more water they settle more rapidly, with better clarification. Theoretically, air may be inferior to mechanical flocculation for immediate settling because some of the air is retained mechanically by the floc, making it lighter. Another consideration is that establishment of aerobic conditions hastens the bacterial decomposition of the sludge, accompanied by CO_2 formation, sometimes rapidly enough to float some of the sludge, except when the sewage is alkaline. In either case the settled sludge would be thinner than mechanically flocculated sludge and therefore aeration may tend to defeat the main purpose of flocculation, namely sedimentation.

Odor Control.—It has been found in some cases where odors have been materially decreased by chemical treatment. H_2S is oxidized by Cl_2 to HCl and sulphur; with lime, it forms a practically stable CaS in neutral or alkaline solution; with iron, the unstable FeS results, which liberates H_2S at any alkalinity. Therefore for H_2S control, lime or chlorine would seem decidedly better than iron salts. However, H_2S is only a part of the odor found around the average sewage plant. The amines, amino acids and decomposed fats or greases present the worst

odor problem. The amines and amino acids form complex iron compounds, and fatty acids form iron soaps, and therefore we find that, practically, iron salts are effective for odor control.

Chemical Costs.—The chemicals which have application in the sewage field have shown marked decline in prices during the past two years and have shown consistent declines during the past ten years. The indications for the future are that this tendency will continue to hold, particularly with increased consumption and cheaper handling costs. On the other hand, costs of biologic treatment are fairly well standardized for various degrees of treatment and have, after many years' use, attained efficiencies which are difficult to improve very extensively. The treatment with chemicals requires considerably less time than either activated sludge or sprinkling filters so that the tank space and equipment necessary are usually only a fraction of the space and equipment required for biologic treatment. Odors from chemical plants can be controlled and destroyed, when necessary, so that plants can be economically located and thus eliminate original and maintenance costs on long sewer lines and pumping stations. Overloaded existing plants can be supplemented with some chemical treatment to give satisfactory conditions in many places, which otherwise would require a new plant or expensive new construction added to the old one.

The quantities of chemicals necessary for treatment may be decidedly decreased when we learn more about the optimum activities and conditions for efficient coagulation. The quantities now being used at various plants show wide differences, but some of the chemicals used could undoubtedly be replaced by acid or salts to obtain the optimum activity point or by the addition of inert bulk producing aids to precipitation, such as ground paper, and thereby reduce the coagulant requirement in some cases. Addition of inert materials such as clay and paper pulp to serve as a nucleus for floc particles effects, in many cases, a saving in chemical cost.

Chemicals used extensively in sewage treatment as quoted in yearly market prices from *Oil Paint and Drug Reporter*.

	1000 lb. year imports	Cost per 100 lb.	
1924	115	$5.75	
25	63	5.90	
26	187	9.50	
27	528	2.90	
28	665	2.80	Cheaper chlorine
29	923	2.70	and production
30	946	2.70	increases in
1931	842	2.60	domestic plants.

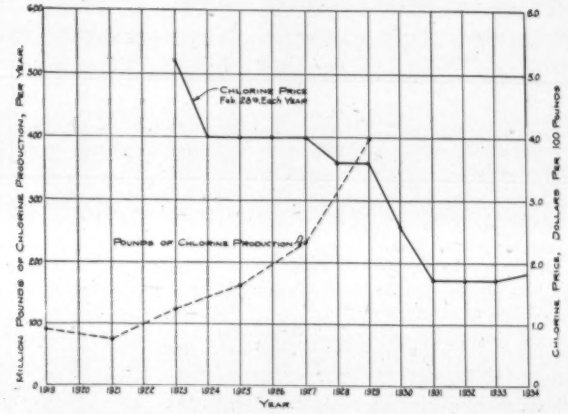
Chlorine Price
Feb. 28th Each Year
Pounds of Chlorine Production
Million Pounds of Chlorine Production, Per Year.
Chlorine Price, Dollars Per 100 Pounds
Year

FIG. 1. Production and cost of chlorine. Data from Bi-annual Census of Manufacturers, U. S. Department of Commerce. From *Drug and Chemical Markets.*

Ferric chloride is now offered in tank cars at \$1.44 to \$1.56 per 100 lb. (anhydrous $FeCl_3$), F.O.B. works. Commercial aluminum sulphate, 1926–1930, sold at \$1.40 per 100 lb. and since that time has been selling at \$1.25 per 100 lb. Commercial chloride of lime, 1926–1930, sold at \$2.00 per 100 lb. and since has been selling at \$1.90 per 100 lb. in large quantities. All of these chemicals have shown marked increases in quality and adaptability for the fields in which they have found application.

SUMMARY

The impurities of fresh domestic sewage are largely insoluble and colloidal matter with relatively small amounts of soluble material. Bacterial and catalytic decomposition reduces the insoluble and increases the soluble impurities, with consequent decreases in facility for clarification and purification. If such a sewage is kept in the fresh state, removals of 60 to 75 per cent B.O.D. and 60 to 75 per cent suspended solids, without effluent filtration, can probably be most economically realized through chemical treatment. Additional 15 per cent B.O.D. and 20 per cent suspended solids removals are possible with final rapid filtration.

Chemical treatment affords the necessary flexibility required for general sewage and waste purification.

Removal of solids and colloidal matter apparently goes through the same fundamental process in either a chemical or biologic plant with the advantage of considerably closer control using chemicals. Overloaded biologic plants are being successfully supplemented with partial chemical sedimentation.

Efficiency of chemical treatment is vitally dependent on the reactivity status of the sewage with respect to the chemicals added.

Ferrous iron seems to be practically useless until oxidized to the ferric state. Air is inferior to mechanical flocculation except in special cases where necessary to provide oxygen to maintain the iron in an oxidized state.

The sludge obtained from chemical processes has shown characteristics much more adaptable to final disposal, by any of the methods now used, than biologic sludge.

Odor nuisances are minimized through chemical treatment, therefore permitting better and more economical location of new plants.

Costs of chemicals have shown a steady gradual decline over a period of thirty years and the tendency is still in that direction. Sales studies show that chemical markets are singularly free from violent price fluctuations.

Discussion

By L. L. Hedgepeth

Pennsylvania Salt Mfg. Co., Philadelphia

The author has so logically established his case for chemical precipitation that a better title would have been *The Why of Chemical Treatment*. In analyzing this paper one observes four orderly steps of argument:

1. The method of removal of the colloidally suspended material is the phase of sewage treatment which differentiates the various methods of complete treatment.

2. In every case—biological or chemical—removal of colloidal matter is accomplished by mutual attraction of oppositely charged particles and is, therefore, a problem of colloid chemistry.

3. The point of optimum coagulation can be more easily maintained by chemical precipitation than with other methods.

4. The price of chemicals is not subject to violent fluctuations as commonly supposed but is sufficiently steady to permit accurate estimates as to probable operating costs over the life of the plant.

Paper Needs Proof of Colloidal Assumption.—If the author is correct in his assumption that colloidally dispersed particles comprise the

majority of the non-settleable matter, then his logic is inescapable. I understand that he has done considerable work on this and it is unfortunate that this paper does not include the experiments on which his conclusion is based.

Chemical Precipitation Accentuates Personal Problem.—It seems to me that our advanced knowledge of chemical and physical behavior enables us to adapt modern chemical methods to sewage disposal, but such processes will require a high degree of technical intelligence among the operators of such a plant.

The juggling of municipal jobs during the depression makes one conclude that our new knowledge of chemical behavior will be of little assistance in increasing chemical precipitation efficiency unless the operator's job is made more stable.

Active Carbons and Clays Have Potentialities.—The reference to activated carbon is interesting, particularly when we consider the rapid price decline of the powdered forms.

If trade rumors of 2 cent or less than 2 cent carbon are correct, and with bleaching clay at $6.50 per ton, it would seem logical to consider the adsorptive materials as potentially efficient agents with which to still further increase the effectiveness of chemical precipitation.

Sewage Works Operation

SEWAGE TREATMENT IN GREENWICH, CONNECTICUT *

By Guy E. Griffin

Sanitary Engineer, Greenwich Sewer Commission

Greenwich is a high class residential town situated on Long Island Sound about thirty miles from New York City. It is made up of four main sections, each having a sewer system and sewage treatment plant. East Port Chester is situated on ground sloping mainly to the Byram River. Greenwich, proper, formerly the borough, drains to Indian Harbor. Cos Cob lies along Cos Cob Harbor and the Mianus River, while Old Greenwich surrounds Greenwich Cove. One portion of the town, Belle Haven, has a private sewerage system with septic tanks and most of the large estates have residential systems. Low ridges separate the four main drainage areas. Topographical conditions make it necessary to provide small, automatic pumping stations for six subdistricts at Old Greenwich and one at East Port Chester. The original plants and pumping stations were designed by Clyde Potts. The administration of the sewerage system and treatment plants is carried out by an elected Sewer Commission of three members, Wm. Jay Willson, Chairman, Andrew J. Post, Jr., and A. P. Mazza.

East Port Chester Plant.—The East Port Chester plant, built in 1917, consisted at first of three septic tanks and a small building to house an open well into which sludge was drawn from the tanks, a centrifugal sludge pump, a chlorine contact chamber discharging over a rectangular weir, and a chlorinating machine. It was originally intended that the sludge would be pumped into a barge in the Byram River and dumped at sea. Later a small open sludge-drying bed was built at one side of the building and still later two larger open beds were constructed. These have since been covered by a glass enclosure.

Each septic tank really consists of two sections separated by a concrete wall about one-third the distance from the inlet to outlet end. A vertical 2-foot slot, provided with baffle grooves, at the center of this wall extends from the top to within 4½ feet of the bottom. A 12-inch pipe through the wall below this slot is provided with a flap on the outlet side. The floor of the tank slopes from the ends and sides to a sludge

* Presented before the 1934 Spring Meeting of the New England Sewage Works Association, Greenwich, Conn., April 30, 1934.

outlet on the tank inlet side of the baffle wall. This outlet is provided with a plug valve.

The use of the open sludge well in the building was eliminated about two years ago by piping directly through it from the tanks to the sludge

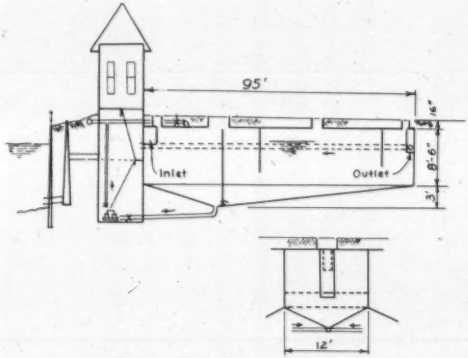

FIG. 1.—East Port Chester Tanks.

pump. This change did away with a damp, sometimes offensive and possibly a dangerous condition in the building.

The present method of operating this plant is to allow the sewage to flow through Tank 1 for a period of two or three months, depending on the quantity of solids accumulating in the tank. The flow is then changed to Tank 2, from which all sludge has been completely removed. Digested sludge is then pumped from Tank 3 to Tank 1 to completely fill it and hasten digestion of the raw sludge. This digested sludge used for seeding amounts to a 2-foot depth or about 27 per cent of the tank contents. For a 6-foot depth of raw sludge and scum in the first section, and 3 feet in the second section of the tank, the ratio of seeding material to raw sludge is approximately 115 per cent. The remaining digested sludge is then pumped to the sludge beds for drying. During the summer of 1933 one tank operated in this manner produced well digested sludge in a month.

A strong sewage with a high pH is treated by this plant as shown in Table I. The indicated strength of the East Port Chester sewage may be somewhat high due to the fact that the samples are collected only in the daytime. This comment holds true to some extent with respect to the results of analyses of the sewage from the other districts, but probably to less extent than in the case of the East Port Chester district, where daytime industries are more important.

TABLE I.—*East Port Chester—Sewage Flow and Analyses*
Averages for 4-Week Periods—1933

Period	Flow Thous. Gal. Daily*	Susp. Solids, P.P.M.			Oxygen Cons'd, P.P.M.			pH		B.O.D., P.P.M.‡			Chlorides	
		Inf.	Eff.	% Removal	Inf.	Eff.	% Removal	Inf.	Eff.	Inf.	Eff.	% Removal	Inf.	Eff.
Jan. 1–Jan. 28	313	243	49	80	221	120	46	8.0	7.6				56	52
Jan. 29–Feb. 25	333	306	36	88.2	195	65	66.8	8.0	7.3				72	50
Feb. 26–Mar. 25	490	244	34	86.1	162	77	52.7	8.0	7.2	260	210	19.2	67	48
Mar. 26–Apr. 22	571	204	38	81.4	155	76	51.1	7.6	7.0				50	46
Apr. 23–May 20	340	269	38	86.0	217	88	59.6	7.2	7.0				123	123
May 21–June 17	253	346	38	89.1	349	102	70.8	7.6	6.4			—	81	146
June 18–July 15	247	468	51	89.1	255	138	45.9	7.7	6.0	560	260	53.6	75	230
July 16–Aug. 12	214	494	51	90.0	245	94	61.8	7.4	6.3				71	131
Aug. 13–Sept. 9	332	344	37	89.2	205	41	80.0	7.4	6.8				72	81
Sept. 10–Oct. 7	442	326	29	91.1	202	79	60.9	7.4	6.8				73	65
Oct. 8–Nov. 4	237	374	48	87.2	194	77	60.3	7.8	6.9	420	230	45.2	73	55
Nov. 5–Dec. 2	208	326	34	89.6	206	82	60.2	7.6	7.1				61	48
Dec. 3–Dec. 30	217	344	39	88.7	216	75	65.3	7.6	7.2				64	44
Average	323	330	40	87.9	217	86	60.4						72	86
Maximum	1100†	494	51	91.1	349	138	80.0						123	230
Minimum	125†	204	29	80.0	155	41	45.9						50	44

* Based on observed rates 8 a.m.–4 p.m.
† Maximum and minimum days.
‡ From analyses of samples during one day in period by State Dept. of Health.

In the plant effluent the suspended solids varied from 29 to 51 and averaged 40 p.p.m. during 1933. This represents a percentage removal of suspended solids ranging from 80 to 91.1 and averaging 87.9 per cent. The oxygen consumed value ranged from 41 to 138 and averaged 86 p.p.m. For oxygen consumed the reduction varied from 45.9 to 80.0 and averaged 60.4 per cent. The pH of the effluent varied from 7.7 to 5.3. The fairly high pH value of the raw sewage is due to wastes from a laundry and probably plays an important part in the satisfactory sludge digestion. The theoretical detention period varied from 12 to 1.4 and averaged 4.7 hours for a clean tank.

As an experiment some digested sludge was left in one tank when it was put into service again. After a few days most of this sludge rose to the surface and black particles of it passed off in the effluent. It was concluded that better results were obtained by starting with a clean tank and seeding the raw sludge after the tank was put out of service for sedimentation.

Digested sludge pumped to the beds during 1933 amounted to 22,000 cu. ft. This wet sludge averaged 6 per cent solids of which the volatile matter averaged 53.7 per cent. Dried sludge removed from the beds amounted to 4,180 cu. ft. All of the dried sludge was taken by residents for fertilizer. No charge was made for it.

Grass Island Plant.—This plant built in 1918 consists of 10 Imhoff tanks, and 5 open sludge beds totaling 9,600 sq. ft. in area. Originally there were only 2 sludge beds of 3,200 sq. ft. but 3 beds have since been added. A building houses a covered sludge well, a centrifugal sludge pump for dosing the beds, a centrifugal pump for furnishing settled sewage to hose the gas vents and wash down the tanks, a chlorine contact chamber discharging over a rectangular weir and a chlorinating machine. Sewage flows through the plant by gravity.

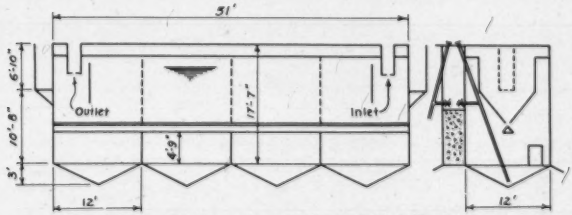

FIG. 2.—Sections through Grass Island Tanks.

The Imhoff tanks are typical of the period in which they were designed, being rather shallow (Fig. 2) as compared with more modern tanks.

The 3-foot opening between each of the four sludge compartments is not large enough to allow much exchange of sludge between the compartments, and sludge soundings and pH tests always indicate different conditions in each compartment.

The sludge space is insufficient to allow storage of enough digested sludge to seed the fresh solids, and considerable foaming results.

Lime has been used to a considerable extent in an effort to control foaming but with little success. It has been added dry and slaked on the surface of the gas vents, then mixed in by plunging the vents with sticks. It has also been applied through the vents as a slurry and some years ago introduced into the sludge compartment as milk of lime. Adding lime dry or in a slurry does not give a good mixing with the sludge, and sampling has shown that much of the lime deposited on the slope below the gas vents. Samples of scum from foaming gas vents have shown a pH of 7, which was higher than in tanks not foaming.

A fairly high level of digested sludge is maintained in the tanks by drawing only small quantities after determining the sludge level by soundings. During the summer these withdrawals are made about once a month. The sludge is not drawn directly to the drying beds but into the sludge well which has previously been emptied. At least an additional month of digestion is thus secured in the well and analysis has shown a difference of 4.5 per cent in the volatile solids as a result. Wet sludge pumped to the beds during 1933 amounted to 30,130 cu. ft. This sludge averaged 5.2 per cent solids, of which the volatile matter averaged 53.9 per cent. Dry sludge removed from the beds amounted to 5,550 cu. ft. A small proportion of this was taken by residents and the balance by the Park Department.

Scum in the gas vents is broken up frequently either by plunging with sticks or hosing with settled sewage pumped through fire hose and nozzle. As an experiment the scum in one gas vent was not broken up for a period of several months. As a result the scum layer increased until it was below the level of the slots. The slopes of the settling compartments are scraped down daily, passing the scraper down through the slots to clear them.

Late in 1932 a grit chamber was completed on each of the trunk sewers leading to the plant. These chambers contain perforated pipes laid longitudinally in the bottom, through which water from a hydrant is flushed weekly to remove organic matter which may have settled with the grit. Before the installation of these chambers grit had accumulated to such an extent in one of the Imhoff tanks that sludge could not be drawn from it. The tank had to be pumped out and the grit removed with a "mud hog" pump.

Table II gives a summary of sewage flow and analyses for this plant.

TABLE II.—*Grass Island—Sewage Flow and Analyses*
Averages for 4-Week Periods—1933

Period	Flow M.G.D. *	Susp. Solids, P.P.M.			Oxygen Cons'd, P.P.M.			pH		B.O.D., P.P.M.‡			Chlorides	
		Inf.	Eff.	% Removal	Inf.	Eff.	% Removal	Inf.	Eff.	Inf.	Eff.	% Removal	Inf.	Eff.
Jan. 1–Jan. 28	1.95	208	46	78	172	88	49.0	7.0	6.9	190	120	36.8	28	33
Jan. 29–Feb. 25	2.47	99	42	57.8	119	69	42.0	7.1	6.9				33	28
Feb. 26–Mar. 25	3.48	90	35	61.2	93	57	38.8	7.1	7.0				39	34
Mar. 26–Apr. 22	3.82	188	31	83.5	139	50	64.1	6.9	6.9	91	78	14.3	26	25
Apr. 23–May 20	2.42	126	37	70.8	123	67	45.6	7.0	6.8				36	35
May 21–June 17	1.84	134	51	62.0	115	74	35.6	7.1	6.6				36	47
June 18–July 15	1.57	265	55	79.2	176	88	50.0	6.9	6.5	350	160	54.2	36	60
July 16–Aug. 12	1.36	214	56	73.9	158	77	51.2	7.0	6.5				41	65
Aug. 13–Sept. 9	2.18	215	37	82.8	133	53	60.1	7.0	6.6				33	49
Sept. 10–Oct. 7	2.60	100	34	66.0	93	60	35.5	7.0	6.6				35	44
Oct. 8–Nov. 4	1.95	372	49	86.8	167	75	55.1	7.1	6.8	230	120	47.8	31	62
Nov. 5–Dec. 2	1.73	172	42	75.6	137	84	38.7	7.1	6.9				30	26
Dec. 3–Dec. 30	2.05	246	50	79.3	168	80	52.4	7.1	6.9				26	22
Average	2.26	187	44	76.5	138	71	48.6						33	41
Maximum	5.72†	265	56	86.8	176	88	64.1						41	65
Minimum	1.18†	90	31	57.8	93	50	35.5						26	22

* Based on observed rates 8 a.m.–4 p.m.
† Maximum and minimum days.
‡ From analyses of samples during one day in period by State Dept. of Health.

The sewage is weak due to a large proportion of ground-water infiltration.

Cos Cob Plant.—This plant, built in 1930, has five septic tanks to which all the sewage is pumped. The incoming gravity sewer discharges into a suction well. Vertical centrifugal pumps are provided in a dry pit adjacent to the suction well, with the motors on the ground floor of the pumping station. There are two sewage pumps with a combined capacity of 3 m.g.d. and an 8-inch vertical centrifugal sludge pump which may also be used for sewage. Sludge is drawn by gravity from the tanks through manholes to a covered sludge well at one side of the sewage well. An auxiliary gasoline engine-generator set provides current in case of power failure. The sludge beds are built on top of the tanks and drain back into them. A glass enclosure covers both the beds and the tanks.

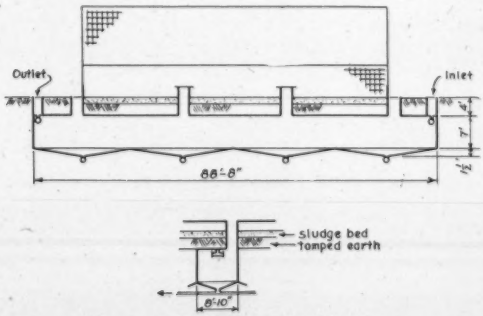

FIG. 3.—Sections through Cos Cob Tanks.

The septic tanks differ from those at East Port Chester in several respects. The inlet to each tank is through a submerged cast-iron tee opening from the bottom of a channel crossing the end of all five tanks. The outlet is similar at the opposite end. The flow line in the influent and effluent channels is about a foot above the roof of the tanks, thus submerging the scum. There are no baffles in the tanks. Each tank has four sludge hoppers and outlets and provision is made for returning sludge to one end of each tank. By-passes along the sides of the tanks were provided to allow reversing the direction of flow. The hydraulics are such that this does not work out well in practice. The settled sewage passes over a rectangular weir into a baffled chlorine contact chamber, and then out to the harbor.

The tanks are being operated in a similar manner to those at East

Port Chester. Because of the submerged roof, however, it is necessary to pump out supernatant sewage to the tank being used for sedimentation in order to seed a tank with digested sludge. After seeding, the contents of the tank are circulated through the sludge pump to mix the seeding material with the raw sludge. Some lime has been used to raise the pH value. One tank treated in this manner foamed slightly for a few days, then quickly subsided. During the period of two or three months that a tank is being used for sedimentation a scum layer forms, varying in depth from a few inches at the outlet end to 4 or 5 feet near the middle. During the period of digestion this scum thickness decreases but does not entirely disappear. In spite of the suppressed roof the scum is comparatively low in moisture content and requires breaking up with a hose stream to flush it out through the sludge outlets when the tank is cleaned. The pH of the scum at both East Port Chester and Cos Cob has often been found to be slightly higher than that of the sludge, but the scum is usually not so well digested. The volume of wet sludge applied to the drying beds during 1933 was 15,933 cu. ft. The dry solids in this sludge averaged 1.9 per cent of which the volatile solids averaged 53.1 per cent. The dried sludge removed from the beds totaled 1,757 cu. ft. All of this was taken by residents. Table III summarizes the 1933 flow and analytical data.

Old Greenwich Plant.—This plant, built in 1926, consisted of three septic tanks, each with two sections with suppressed roofs and submerged inlet and outlet. There were two sludge beds under a glass enclosure. A building housed a sludge well, a centrifugal sludge pump, a baffled chlorine contact chamber and a separate room, as at Cos Cob, for chlorine equipment.

At the beginning of 1932 it became desirable to make changes at this plant. Several investigations had been made by various engineers to determine what changes and additions would be necessary and early in 1932 the Commission retained Metcalf & Eddy to design and supervise construction of changes and additions to the plant.

The first change was the reconstruction of the sludge beds. The old beds were found to be badly clogged, not only in the filtering material but in the underdrains as well. New underdrains and new material in layers varying in size from coarse stone at the bottom and around the drains, to sand at the top, were placed on top of the old bed.

This allowed some of the sludge to be removed from the septic tanks, so that they might operate more properly until the additions to the plant were completed. In March, 1932, sludge and scum soundings indicated a total volume of 10,900 cu. ft. of sludge and scum in the three tanks, out of a total tank capacity of 19,200 cu. ft. Due to the considerable accumulation of sludge in each of the tanks it was necessary at

TABLE III.—*Cos Cob—Sewage Flow and Analyses*
Averages for 4-Week Periods—1933

Period	Flow Thous. Gal. Daily	Susp. Solids, P.P.M.			Oxygen Cons'd, P.P.M.			pH		B.O.D., P.P.M.†			Chlorides	
		Inf.	Eff.	% Removal	Inf.	Eff.	% Removal	Inf.	Eff.	Inf.	Eff.	% Removal	Inf.	Eff.
Jan. 1–Jan. 28	390	150	33	78	170	102	40	7.3	7.1				555	690
Jan. 29–Feb. 25	520	123	50	59.4	112	70	37.4	7.3	7.1				685	734
Feb. 26–Mar. 25	735	85	34	60.0	83	52	37.4	7.1	6.9				382	411
Mar. 26–Apr. 22	893	45	29	35.6	69	58	16.0	7.0	7.0				310	340
Apr. 23–May 20	497	85	36	57.8	90	68	24.4	7.2	7.0				521	620
May 21–June 17	379	135	45	66.8	102	73	28.4	7.2	6.8	290	170	41.4	737	881
June 18–July 15	298	140	74	47.2	132	103	21.9	7.1	6.9				1075	1435
July 16–Aug. 12	247	171	77	55.1	148	112	24.3	7.2	6.8				1777	2198
Aug. 13–Sept. 9	392	157	65	58.6	124	71	42.7	7.1	6.8				1419	1544
Sept. 10–Oct. 7	598	60	34	43.3	85	60	29.4	7.0	6.8	130	100	23.1	817	798
Oct. 8–Nov. 4	390	139	65	53.2	120	83	30.8	7.2	7.0				788	856
Nov. 5–Dec. 2	350	154	59	61.7	136	88	35.3	7.3	7.1				766	827
Dec. 3–Dec. 30	407	118	54	54.2	115	84	27.0	7.2	7.0				667	758
Average	469	120	50	58.3	114	79	30.7						808	930
Maximum	1988*	157	77	78.0	170	112	42.7						1777	2198
Minimum	211*	45	29	35.6	69	52	16.0						310	340

* Maximum and minimum days.
† From analyses of samples during one day by State Dept. of Health.

TABLE IV.—*Old Greenwich*

*Results of Adding Lime to Septic Tank No. 2 *—1932*

Date	Section No. 1						Section No. 2					
	Scum		Water, pH	Sludge		Lime Added	Scum		Water, pH	Sludge		Lime Added
	Depth	pH		Depth	pH		Depth	pH		Depth	pH	
Apr. 22						280 Lb.						280 Lb.
Apr. 28	0	7.0	6.8	3½ ft.	8.6		1 ft.	6.4	6.9	2½ ft.	8.6	
May 6	1½ ft.	6.6	6.6	3½ ft.	8.4			6.2	6.5		6.9	
May 19	3½ ft.	6.4	6.6	3 ft.	7.5		4½ ft.	6.1	6.2	3 ft.	6.2	
June 13	1 ft.	6.6	6.7	3½ ft.	7.1		2½ ft.	6.0	6.7	4 ft.	6.6	
June 21						280 Lb.						280 Lb.
June 27	2 in.		7.4	3 ft.	7.6		6 in.		7.2	3 ft.	6.9	
July 12	Cleaned July 6						2 ft.	6.2	7.0	2 ft.	7.0	
July 28							2 ft.	7.6	7.0	3 ft.	7.2	
July 30							Cleaned					

* In service for sedimentation Dec. 28, 1931–Apr. 22, 1932—116 days. Digesting Apr. 22–July 30—99 days.

Sludge Analyses

	Volatile Matter	pH
July 6—Sect. 1	57.8%	6.4
July 30—Sect. 2	57.2%	7.3

first to remove a portion of the partially digested sludge from each tank, it not being possible to thoroughly clean any one tank. However, by June 6, half of one tank, and by July 30 both halves of another tank were cleaned. Some of the sludge in the tanks was conditioned by recirculating with a "mud hog" and adding milk of lime to it. In this process of conditioning the sludge, 3,430 lb. of lime were used. As a result of this treatment of the sludge, fair digestion was finally established in about half the time that sludge previously remained in the tanks, with a marked reduction in the odors given off both from the tanks and from the sludge when applied to the drying beds. The period of operation of each tank for sedimentation was shortened to about half the former time, to ensure better removal of solids and thus a better effluent. By the middle of October the sludge volumes had been reduced to 5,300 cu. ft. as estimated in the tanks. Table IV gives some results of liming.

In an effort to minimize odors from some of the sludge, dry chloride of lime was sprinkled on the sand before dosing a bed. It was interesting to find that not only were odors reduced but draining was hastened. This was checked in the laboratory by placing a small quantity of chloride of lime in the bottom of one of two cylinders and filling both with sludge. Separation of water at the bottom of the cylinder containing the chloride of lime would appear much in advance of that in the other cylinder. Residual chlorine tests of the bed effluent indicated satisfactory chlorination. Unfortunately the application of chloride of lime in this manner is a disagreeable job requiring a gas mask, and there was indication later of some caking of the sand surface. The rate of application was 50 lb. of dry chloride of lime per thousand sq. ft. of bed surface.

Kuchar Bros. of Montvale, N. J., were the lowest bidders for the construction work and started work on the contract the middle of May, 1932.

By November 1, 1932, the additions were completed. They consist of a bar screen with 1½-inch openings, two covered plain sedimentation tanks equipped with Link-Belt scrapers, a heated separate sludge-digestion tank, two additional sludge beds under a glass enclosure, the necessary pumps for moving the sludge, and a combination gas and coal-fired boiler for utilizing the sludge gas in heating the digestion tank and building.

A new small building houses the rack chamber, the motor for driving the sludge collector, a Rex Simplex pump for pumping the raw sludge to the digestion tank, and valves on sewage and sludge piping. A goose-neck branch pipe from the sludge line discharges through a quick-opening valve into a bell-mouth pipe located on the first floor, so

that the operator may observe the character of the sludge being pumped.

The digestion tank, 20 ft. in diameter and 25 ft. deep, has a floating cover. Five 1½-inch pipe coils in the lower half of the tank provide for the heating. The hot water is circulated through this coil and a coil in the boiler by a centrifugal pump.

At one side of the tank is a decanting chamber and sampling gallery. In the decanting chamber are four top water draw-off pipes spaced 2 ft. 3 inches vertically, and an overflow. The draw-off valves are operated by gate stands on top. The sludge draw-off valve at the bottom is also operated by a gate stand on top. In the sampling gallery flexible copper

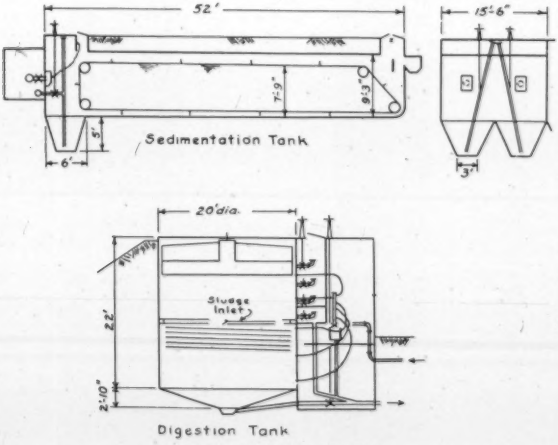

FIG. 4.—Old Greenwich Tanks.

tubing connects 2-inch sampling pipes spaced 4 feet apart vertically, through quick-opening valves into a manifold which discharges into a sink. The lowest sampling pipe is a foot above the bottom slope of the tank. These pipes make possible easy and quick sampling for determining the approximate sludge level, and the temperature and pH of the sludge at the various levels. Provision is made for flushing the pipes should they become clogged.

Two flame traps in parallel are provided on the gas main in the boiler room. Beyond these the gas line branches to the gas burner in the boiler and to a pressure-relief valve on a line running to a waste-gas burner outside. This waste-gas burner is provided with a pilot

flame and a spark plug for ignition. Both the gas main and the waste pipe drain to a condensate trap. The gas line to the boiler and the waste line are each provided with thin plate orifices with pressure tubes leading to Bailey flow recorders located on a panel in the laboratory. The panel also carries temperature recorders for registering the temperature of the outdoor air, the temperature of the sludge near the center of the digestion tank, and the temperature of the circulating water to and from the coils in the tank.

The International boiler is designed for both gas and coal fuel, and besides heating water in the coil furnishes steam to space heaters in the building. The Webster gas burner is of the regenerative type with a Minneapolis-Honeywell automatic gas valve, controlled either by steam pressure or boiler water temperature. A pilot flame is so arranged that should it be extinguished the gas valve cannot open.

The new sludge-bed enclosure furnished by the American-Moniger Co. has top sashes that swing out and in-swinging bottom sashes on all four sides. Both the old and new enclosures were equipped with power outlets for operating a portable Link-Belt conveyor provided for loading dried sludge into a truck.

Particular attention was given to landscaping the grounds about the plant because of its location in a high class residential section and adjacent to a much traveled thoroughfare.

The new sedimentation tanks were put in service October 27 and the digestion tank October 31, 1932.

At first, the sludge collectors were operated for 30 minutes each day and the sludge was allowed to concentrate in the pits until just prior to the scraping, on alternate days, when it was pumped over to the digestion tank. The period of scraping allowed one flight to make a complete traverse of the bottom which later did not appear to be sufficient and the period was increased to one hour. During the summer the raw sludge became septic in the pits and some rose to the surface. The pumping schedule was then changed to every day except Sunday and followed the scraping. This reduced the amount of sludge rising to the surface over the hoppers but didn't completely eliminate it. During the period of scraping and removal of scum just following, an appreciable quantity of fine material escaped beneath the effluent baffle and over the effluent weir. The 12-inch depth of baffle was increased to 24 inches which helped but did not entirely eliminate this difficulty. Later during this period of operation two removable screens of $\frac{1}{8}$-inch mesh were placed in the effluent channel and were found to remove practically all of the fine material.

In starting the digestion tank it was filled about half full with sludge which had been conditioned and partly digested in one of the old septic

tanks. Sufficient very liquid sludge from the septic tank last in service was also added to float the cover. On the alternate days when raw sludge was not being pumped, small quantities of sludge from the septic tanks were pumped to the digestion tank. This procedure was continued until February 9, 1933, when all the septic tanks had been cleaned. The last of this sludge, which had been held for several months in the septic tank, was too well digested to produce much gas. No lime was added to the digestion tank during this period. The seeding sludge had a pH of 6.5 and the raw sludge varied from pH 5.3 to 6.3. The pH of the sludge in the tank increased slowly until it had reached

FIG. 5.—Old Greenwich Sewage Works, showing proximity of dwellings.

7.1 January 4, 1933, and remained there until March 9, 1933, when it had dropped to 6.8 and has consistently remained between there and 6.9.

A laboratory experiment was carried out in bottles to determine the effect of lime. To each of two bottles, sludge from the digestion tank at pH 6.7 was added, but to one sufficient lime was added to raise the pH to 7.5. Both bottles were placed in a water bath kept at the tank temperature. The volume of gas produced by each was measured daily. The control sample gave off gas immediately but the adjusted sample produced very little gas for a week, then started producing at a much greater rate than the control, but at the end of two months was considerably behind the control in total quantity of gas produced. An initial

retarding effect in gas production has been observed several times after small additions of lime to the digestion tank.

A considerable quantity of digested sludge is kept in the tank for seeding the raw sluge. Computations indicate that the additions of raw sludge are considerably less than 15 per cent of the seeding material by volume or less than 5 per cent by weight of dry solids.

The temperature of the digesting sludge has been maintained at approximately 80° F., varying from 75 to 92°. The optimum gas production appears to occur at a temperature of 80 to 83° F.

The top water is decanted to one of the old septic tanks just prior to pumping raw sludge. This decanted liquor contains from 530 to 1,760 p.p.m. suspended solids, which in passing through the septic tank are reduced to 20–48 p.p.m., based on daily analyses for one week. The septic tank has been in service for this purpose for several months. The settled liquor goes to the inlet of the sedimentation tanks.

As an experiment the digestion tank liquor was decanted daily for one week to one of the sludge beds. The effluent from the bed averaged 28 p.p.m. suspended solids and had only a slight yellow color.

Digested sludge from the digestion tank has been drawn to the sludge beds once or twice each month. It has averaged 7 per cent solids, with 50 per cent volatile on a dry basis. Several residences are within a few hundred feet and the nearest about 50 feet from the sludge beds, yet none of the residents have reported any odor. The average dose on the bed is 4 inches, which drains overnight and dries with favorable weather in a week or ten days. A total of 21,391 cu. ft. of wet sludge was applied to the beds during 1933. This includes some sludge from the septic tanks. Dried sludge removed from the beds amounted to 3,747 cu. ft. All of the dried sludge has been taken by residents or the park department for fertilizing lawns and shrubs. At present no charge is made for it.

The gas yield at first was low but suddenly increased near the end of the first month of operation. It then continued high until all the old sludge from the septic tanks had been added. It then decreased to a normal rate for the regular additions of raw sludge. A computation in late February, 1933, indicated a yield of 0.7 cu. ft. per capita per day contributing, or 12.2 cu. ft. per lb. of dry volatile solids added. This yield may have been somewhat influenced by the previous additions of septic tank sludge as later gas yields appear to be nearer 0.5 cu. ft. per capita per day. A slight amount of foaming was experienced on only one occasion after a fairly heavy dose of septic tank sludge. The floating cover tipped sufficiently once to allow the escape of gas under the edge, due apparently to frost formation clogging the waste gas line. During the past winter condensation has frozen on two oc-

casions in a swivel joint at the top of the gas dome causing a stoppage of gas flow, but not sufficient gas accumulated to tip the cover. Further freezing at this point was prevented by introducing a handful of salt into this pocket.

An analysis of the gas in February, 1933, by the Department of Sanitary Engineering of Harvard University showed 68.0 per cent methane and 30.4 per cent carbon dioxide, with a computed fuel value of 656 B.T.U. at 78° F. An appreciable proportion of hydrogen sulphide is present in the gas and from some of the laboratory burners a strong sulphur dioxide odor is given off when the gas is burned. Table V gives a summary of gas production and Table VI a summary of sewage flow and analytical results.

TABLE V.—*Old Greenwich*

Gas Production and Sludge Temperature

Period	Total	Gas Production, Cu. Ft.			Sludge Temperature, ° F.		
		Daily Aver.	Max. Day	Min. Day	Aver.	Max.	Min.
Nov. 2–Nov. 26, 1932	19,432	772	2259	487	84	92	66
Nov. 27–Dec. 24	90,096	2218	6065	1596	81	84	78
Dec. 25–Dec. 31	33,240	4748	5149	4259	81	84	79
Jan. 1–Jan. 28, 1933	92,969	3320	4520	1722	78	83	72
Jan. 29–Feb. 25	95,706	3418	5300	1958	82	84	76
Feb. 26–Mar. 25	53,610	1915	2285	1361	79	84	74
Mar. 26–Apr. 22	39,360	1405	2108	714	80	84	74
Apr. 23–May 20	60,074	2145	3889	965	83	87	81
May 21–June 17	58,386	2085	3031	797	82	86	78
June 18–July 15	58,285	2082	2781	798	83	85	80
July 16–Aug. 12	61,160	2184	2973	1133	84	89	80
Aug. 13–Sept. 9	73,043	2609	3570	1411	84	90	81
Sept. 10–Oct. 7	62,630	2236	2990	999	85	92	81
Oct. 8–Nov. 4	47,427	1693	2779	336	83	92	76
Nov. 5–Dec. 2	47,191	1685	2428	1125	79	82	75
Dec. 3–Dec. 30	48,237	1722	2461	579	79	82	76
Aver. 1933	61,391	2192			82		
Max. day			5300			92	
Min. day				336			72

Chlorination.—The effluent from each of the plants is chlorinated during the summer from approximately May 1 to October 1. Previous to 1932 chlorine had been purchased in 100 lb. cylinders at a price in

TABLE VI.—*Old Greenwich—Sewage Flow and Analyses*
Averages for 4-Week Periods—1933

Period	Flow Thous. Gal. Daily	Susp. Solids, P.P.M.			Oxygen Cons'd, P.P.M.			pH		B.O.D., P.P.M.†			Chlorides	
		Inf.	Eff.	% Removal	Inf.	Eff.	% Removal	Inf.	Eff.	Inf.	Eff.	% Removal	Inf.	Eff.
Jan. 1–Jan. 28	No record	119	51	57.0	144	97	33.0	7.0	7.1				587	634
Jan. 29–Feb. 25	570	87	34	61.0	87	63	27.6	7.1	7.0				437	574
Feb. 26–Mar. 25	859	62	25	59.8	72	59	18.0	7.0	7.0	110	64	41.8	371	415
Mar. 26–Apr. 22	984	56	20	64.5	62	34	45.2	6.8	6.8				340	357
Apr. 23–May 20	701	84	31	63.2	104	62	40.5	7.1	7.0				398	459
May 21–June 17	603	154	44	71.8	109	63	42.1	7.0	6.9	190	110	42.2	440	499
June 18–July 15	540	150	52	65.3	133	85	36.1	7.1	6.9				412	498
July 16–Aug. 12	514	186	55	70.4	156	90	42.4	7.2	6.8				456	614
Aug. 13–Sept. 9	584	183	42	77.0	122	65	46.7	7.1	6.9				458	499
Sept. 10–Oct. 7	658	158	32	79.7	125	70	44.0	7.0	6.9				384	396
Oct. 8–Nov. 4	499	158	47	70.2	120	79	34.2	7.1	7.0	160	120	25.0	308	357
Nov. 5–Dec. 2	501	151	42	72.2	148	84	43.2	7.1	7.1				272	338
Dec. 3–Dec. 30	588	272	43	84.2	151	73	51.7	7.5	7.1				284	304
Average	633	140	40	71.4	118	71	39.8						396	457
Maximum	1200*	272	55	84.2	156	97	51.7						587	634
Minimum	420*	56	20	57.0	62	34	18.0						272	304

* Maximum and minimum days.

† From analyses of samples during one day in period by State Dept. of Health.

1931 of $5.40 per cwt., not including transportation. By building platforms at the height of a truck at each of the plants it became possible to handle ton containers. In 1932 the price in ton containers was $2.29 per cwt. delivered on the platforms, against a bid of $5.50 per cwt. in 100 lb. cylinders. This represented a saving of $1,926 on 30 tons, or approximately 59 per cent. In addition to the financial saving, practically all labor of handling was eliminated, for once the tanks are delivered on the platform and the valves set vertically they need only to be blown off and connected by heavy copper tubing to the pipe line leading to the chlorinator. No scales were provided for weighing the cylinders as the dosage is governed by the residual chlorine test and the daily application computed from a record of settings of the chlorinator. At the outset considerable difficulty was experienced at East Port Chester due apparently to a leaky tube inside a cylinder allowing liquid chlorine to reach the machine. This caused freezing and the destruction of a rubber float. After locating the difficulty it was overcome by the simple expedient of rolling the tank over and using the other tank valve.

At East Port Chester an experiment in pre-chlorination of the influent to one of the septic tanks was carried out for a time during 1933. The chlorine solution was applied at the narrow inlet to the tank from the end of the chlorinator hose, where it received good mixing. For about a week the required dosage to secure a satisfactory residual, starting with a clean septic tank, was about the same as for post-chlorination. During this period no scum formed in the tank. At the end of this period scum began to form and the required dosage began to increase and continued increasing during the period of the experiment from 16 to 64 p.p.m. This increase was apparently due to the chlorine demand of the increasing sludge accumulation, and seems to show that pre-chlorination of a large septic tank is not economical. Upon returning to post-chlorination with a clean tank the chlorine demand dropped to an average of 15 p.p.m. during the next operating period.

Near the end of the 1933 season pre-chlorination was tried at Old Greenwich. The chlorine was at first applied from the end of a hose and next through a home-made grid placed at the inlet end, just inside one of the sedimentation tanks. The dosage required for one tank was more than for post-chlorination of both tanks and good distribution was not secured. The point of application was then changed to the inlet sewer just ahead of the bar screen. It was then possible to reduce the dosage for both tanks to an amount equal to or slightly less than that for post-chlorination and secure a satisfactory residual after the sewage had passed through the sedimentation tanks and chlorine contact chamber. The pre-chlorination reduced the amount of sludge rising

to the surface over the hoppers and practically eliminated the offensive raw sludge odor which had previously been present in the rack room when pumping and sampling the raw sludge. Table VII gives a summary of chlorination during 1933.

TABLE VII.—*Greenwich, Conn.*

Summary of Chlorination, 1933 *

	East Port Chester	Grass Island	Cos Cob	Old Greenwich	Total
Period	May 13–Oct. 18	May 8–Oct. 10	May 16–Oct. 17	May 8–Oct. 18	
Days	161	156	145	163	
Total Lb.	8,000	32,000	6,000	7 080	53,080
Lb. per Day	50	205	41.5	43.4	
P.P.M.	20.1	12.9	13.1	9.0	
Water Used by Chlorinator					
Total Gal.	485,695	991,240	375,260	—	
Gal. per Day	3,017	6,354	2,588	—	
Gal. per Min.	2.8	4.4	1.8	—	
Gal per Lb. Cl.	60.3	31.0	62.3	—	

* East Port Chester and Grass Island—Wallace & Tiernan vacuum feed chlorinators. Cos Cob—Paradon dry feed machine with water diffuser. Old Greenwich—Wallace & Tiernan—wall type vacuum feed.

Laboratory.—Early in 1932 plans were worked out to utilize one of the rooms of the Old Greenwich plant for a laboratory. Benches and cabinets were installed and equipment selected to use the sludge gas for heating as far as possible. The laboratory was ready to operate by July first and as the digestion tank was not yet completed Pyrofax gas was used until the sludge gas was available. It was interesting to note that the Pyrofax gas made carbon deposits on cold porcelain dishes, while this has never happened with the sludge gas.

Since the installation of the laboratory, weekly composite samples of the influent and effluent at each of the plants have been taken for analysis. Equal portions are taken several times through the 8-hour working day to represent as nearly as possible a 24-hour composite sample. In addition to the analysis of sewage samples, samples of digesting sludge taken about once a month and samples of all sludge drawn to the sludge beds have been analyzed. A mud and dissolved oxygen investigation was made of Greenwich Harbor in 1932 and several such investigations have been made of the Old Greenwich Creek.

Bacterial examinations have been made occasionally, during the summer, of the plant effluents and the Old Greenwich Creek. An article in *Water Works and Sewerage*, December, 1933, described the installation of an Electrolux refrigerator in the laboratory operating on the sludge gas. This has been very satisfactory.

Records.—Prior to 1932 no uniform system of keeping plant records had been adopted. Some records were being kept at each plant, but the system was not uniform. The author prepared record forms for each plant on loose leaf 8½ by 11 inch sheets, which were tried out for several operating periods, making slight changes as necessary, and obtaining approval of the State Department of Health before they were printed. These forms are based on the committee reports which have appeared in *Sewage Works Journal* and are for thirteen four-week periods during the year. Forms were also prepared for reporting the weekly analytical results. At the end of each period the sheets are totaled and averaged and copies typed in the sewer commission office for their files, for the State Department of Health and the laboratory file. The originals are returned to binders at the plants. These records form the basis for periodic and annual reports of which copies are sent to the State Health Department.

Cost Analysis.—Table VIII gives an analysis of the cost of each plant to the end of 1933 and operation costs for 1933. Interest and depreciation have not been included.

The connected population has been computed from the record of sewer maintenance accounts, assuming an average family of five persons. This probably gives a fair estimate for the older plants, East Port Chester and Grass Island, but may be somewhat too high for Cos Cob and Old Greenwich where some accounts may be against property not yet connected.

Salaries, supervision and labor include the salaries of the operators and their assistants at each plant, any additional labor, and the salary of the sanitary engineer divided equally between the four plants. Nothing has been included for the sewer commission or office staff.

Except at Cos Cob none of the power used was for sewage pumping. At Cos Cob all the sewage is pumped at the plant and becomes part of the plant operation. At Old Greenwich the power as metered includes one pumping station located on the plant site, but which actually discharges into the gravity sewer. Separate metering for this station prior to 1932 was available and used to compute the power used by the treatment plant alone. This latter figure does include the small amount of current used by the laboratory. The high figures for unit cost of power at East Port Chester and Grass Island are due to heavy stand-by charges based on motor horse power of the centrifugal sludge pump

TABLE VIII.—*Greenwich, Conn.*
Plant Operation Costs—1933

Plant	East Port Chester	Grass Island	Cos Cob	Old Greenwich
Year Built	1917	1918	1930	1926
Cost of Land	$23,000	10,000	13,830	3,000
Cost of Plant	$17,745	120,000	172,000	100,000
Date of Additions	1929	1932	1932	1932
Cost of Additions	$12,676(a)	3,844(b)	1,154(c)	65,000(d)
Cost of Chlorine Platforms and Piping	$ 351	394	183	234
Total Cost	$53,772	134,238	187,167	168,234
Laboratory Equipment 1932 and 1933				1,168
Connected Population	3,000	8,000	4,000	4,000
Design Population	—	—	—	
Load Factor Per Cent	—	100	—	
Sewage Flow				
Total for year m.g.	118	825	171	231
Gal. per capita—per day	108	282	117	158
Salaries, Supervision and Labor				
Total	$ 2,703	6,795	3,991	4,280
per m.g.	$ 22.91	8.24	23.34	18.53
per capita	$ 0.90	0.85	1.00	1.07
per cent total	70.7	72.1	60.3	71.5
Power				
Total kw. Hr.	121	1,080	29,950	12,500
kw. Hr. per m.g.	1.0	1.3	175	54
Total Cost	$ 494	540	1,192	605
per kw. Hr.	$ 4.09	0.50	.039	.048
per m.g.	$ 4.19	0.65	6.97	2.62
per capita	$ 0.16	.07	0.30	.15
per cent total	12.9	5.7	17.9	10.2
Repairs, Supplies and Miscellaneous				
Total	$ 593	2,055	1,407	1,063
per m.g.	$ 5.02	2.49	8.23	4.60
per capita	$ 0.20	0.26	0.35	0.27
per cent total	15.5	21.8	21.3	17.7
Laboratory Supplies 1933	$ 33	35	33	33
per m.g.	$ 0.28	.04	0.19	0.14
per capita	$ .01	.004	.008	.008
per cent total	0.9	0.4	0.5	0.6
Total Cost of Operation	$ 3,823	9,425	6,623	5,981
per m.g.	$ 32.40	11.42	38.73	25.89
per capita	$ 1.27	1.18	1.66	1.50

Note: (a) Covered sludge beds; (b) open sludge beds; (c) fence; (d) sedimentation tank, covered sludge bed, digestion tank, etc.

units, which are used infrequently. At East Port Chester the large motor and centrifugal pump are being replaced by a plunger pump with much smaller motor. The power charges at Cos Cob and Old Greenwich are based on demand and consumption.

The item "Repairs, Supplies and Miscellaneous" includes the cost of chlorine used, the cost of water for the chlorinators and for flushing, charts for recorders, paint, coal for heating, and all repairs and supplies.

The operation cost for the laboratory includes the ice and chemicals purchased, and plant operation and analysis forms, but does not include any charge for electric current or water used which are included under Old Greenwich.

The author wishes to express his appreciation of the cooperation of the Greenwich Sewer Commission, and assistance of its staff in preparing this paper and the friendly cooperation of the plant operators and their assistants in operating the plants under his supervision since February, 1932. He wishes also to extend his appreciation to E. Sherman Chase of Metcalf & Eddy and to S. M. Ellsworth for their constructive criticism of this paper.

SLIME GROWTHS IN SEWERS *

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Slimes adhering to the inside of sewers may consist of sewage solids, fungus growths or both. This paper deals primarily with slime growths or fungi. They are flowerless plants having the special characteristic of absence of chlorophyll, or green coloring matter, and starch. Hence, one conspicuous attribute is their gray, whitish or brownish color and their slimy nature. Being devoid of chlorophyll they are unable to assimilate inorganic matter and consequently lead either a saprophytic existence, living on dead organic matter, or a parasitic existence upon a living host. Some of them, those in which we are interested, may live a semi-aquatic life.

Though in some instances the growths are intensely aggravating in a sewer system or to sewage works operators, the troubles they cause are comparatively uncommon and usually not continuous. In this paper I shall attempt to describe briefly some members of this group of organisms, review the experience of the Bureau of Sanitary Engineering with such growths in sewers and in streams, and mention some of the methods that have been tried to overcome them.

A number of organisms are involved, among which are *Cladothrix* and *Sphaerotilus*, which may be the same organism, *Leptomitus*, and *Beggiatoa*. *Sphaerotilus natans* is the so-called sewage fungus. This fungus appears as a dirty, cotton-like, gelatinous mass growing in oozy blankets or as long fragments sometimes likened to sheeps'-tails. Color varies from pure white to gray, brown, and sometimes even a dark red. Under the microscope, *Sphaerotilus natans* (1) appears as colorless threads showing a true branching. The filaments consist of rod or oval cells, surrounded by a thin firm sheath. The organisms multiply by spores, thus they are resistant and not easily killed. Another well-known species is *Sphaerotilus dichotomus*. Microscopically it is distinguished from *Sphaerotilus natans* by its false branching rather than true branching. The threads or filaments appear to be branched, but actually the apparent branches are cells which slip out of the sheath laterally and usually manage to break away; occasionally they cling to the sheath and form a thread adherent to the parent plant.

Another fungus which resembles *Sphaerotilus* both in appearance

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and in its habitat is *Leptomitus*. Visually it cannot be distinguished from *Sphaerotilus* except possibly by expert biologists. Microscopically it is also a colorless, branched, threadlike organism, the threads being constricted at intervals into distinct segments with a conspicuous cellulin plug separating them. Sporangia or sacs containing the spores are found at the apex of the threads. Both of these organisms are aerobes. There are probably many variants. There are also many forms of true iron bacteria and fungi but except in special cases they are probably not found in sewage.

Beggiatoa (2) is a third member of the sewage fungi or bacteria, which grows principally in water containing sulphur compounds. It consists of short, compact, colorless threadlike filaments containing numerous sulphur granules, and exhibits an oscillating movement. It differs conspicuously from *Sphaerotilus*, lacking the slimy appearance. The most common species is *Beggiatoa alba*. This organism oxidizes hydrogen sulphide and accumulates sulphur in the form of small spheres, consisting of soft amorphous sulphur which never crystallizes in the living cells. It oxidizes the sulphur to sulphuric acid, which is at once neutralized by the carbonates present into sulphates. Without sulphur the organisms soon die off. They can even live and multiply in liquid containing only traces of organic substances. Approximate optimum reaction for growth is at pH 8. *Beggiatoa* is commonly found in sewage polluted waters but does not cause such difficulties as the large masses of *Sphaerotilus*.

The slimy *Sphaerotilus* or *Sphaerotilus*-like growths have been encountered in California both in sewer systems and submerged in the upper stretches of polluted streams, and certain characteristics have been noted regarding their occurrence. These fungi grow best in water or sewage containing some dissolved oxygen and carbonaceous matter, and which are almost neutral in reaction. In California the majority of cases are found in the North Sierras where water supplies are very soft and cold and sewage is very dilute. European investigators report difficulties in growing the organisms in hard waters but were able to do so in soft waters. Senft (3) gives the chief habitat of these fungi as sewage, especially when containing carbonaceous wastes as from breweries and sugar factories, indicating that wastes containing carbonaceous material promote its growth. Being devoid of chlorophyll, they are unable to extract carbon from atmospheric carbon dioxide and therefore probably split it from carbonaceous matter. This checks with our observations in streams receiving highly carbonaceous wastes as from canneries, wineries and paper mills.

These organisms have given more or less trouble in the sewers, screens, tanks or filters at Dunsmuir, Roseville, and Shastina, Cali-

fornia. I believe the Yosemite works can also point to some troubles. Occasionally one encounters references in the sewage works literature indicating difficulties of similar sort elsewhere. One case I recall (4) was at the Des Plaines plant of the Chicago Sanitary District in 1927, where the light fluffy masses refused to settle in any stage of the activated sludge process. In this case the organism appeared to be a variant of *Sphaerotilus*.

At Choteau, Montana (5), a heavy growth in the sewage collection system was reported in 1922 and 1923. I believe also that Sparks, Nevada, has had an experience with *Sphaerotilus*. Reno is near Sparks and has a similar water.

It is somewhat curious, however, that not all places having an abundant, cold, soft water supply experience these growths in the sewage, indicating that an extremely delicate balance of several factors is necessary. For example, Folsom Prison sewage seems not to have *Sphaerotilus* though all factors seem to be right for it, except that the sewer outfall is so short, only a couple of blocks long, that probably the dissolved oxygen is too high or the sewage is not in a state of suitable food supply for these organisms. In Roseville sewage the *Sphaerotilus* first appears about October 15, increasing gradually to December, then remaining fairly constant until February 1, and gradually disappearing by about March 15. Only one sewer line, to which an olive-packing plant is connected, is affected. This suggests the olive-plant wastes as one important factor. Olive meat contains carbohydrates (6) which may be a source of carbonaceous material for *Sphaerotilus*. It is interesting that the *Sphaerotilus* growths occur about the same time as the busy season at the olive plant.

As a general comment, the aggravating consequences of growths of *Sphaerotilus* include slimy accretions inside the sewers and often merely in particular runs of sewers, as at Roseville; breaking down of fragments and even huge patches of the mats of fungus which come down on sewage treatment works where they clog screens, form ugly floating masses on the surface of settling tanks, interfere with mechanical scrapers in settling tanks, choke filter nozzles and stone beds, and in activated sludge plants give a cloudy, "bulked" effluent.

Where there are reasons to anticipate these growths the design of sewage works and even the choice of process may be involved. So far as I am aware, *Sphaerotilus* presents no problem in a digester, probably because the absence of oxygen is quickly fatal to it.

Sphaerotilus is far more common in streams than in sewage works. Regardless of the location of streams or fresh water ditches receiving sewage or wastes from industries that release much carbonaceous matter, they may exhibit *Sphaerotilus* growths in varying degrees.

Even casual observers have no doubt seen the gray mats and waving threadlike filaments attached to stones, twigs and grass, below most sewer outfalls in fresh water where dilution is moderate. Even ditches carrying sprinkling-filter effluent show bits of gray fungus. The following cases are given as examples of *Sphaerotilus* growths in streams:

Auburn Ravine is a creek having flow of around 20 second feet in summer. It receives first the waste of a 45-ton peach cannery representing a population equivalent to about 6,000. Then 3 miles below is the septic tank outfall of the town of Lincoln with 2,000 population. The dilution is about 2½ second feet per 1,000 population. The *Sphaerotilus* growths cling to debris along the banks and on the creek bottom below the cannery for several hundred feet, then gradually thin out. The growth again increases as the city outlet is passed but it is practically all replaced by green and brown algae ¾ mile downstream. Over this stretch the dissolved oxygen, during a 2-day test period, varied from 12 to 75 per cent of saturation.

Roseville sewage discharges to Linda Creek. *Sphaerotilus* growths were found for a few hundred feet below the outlet, but one mile below the outlet there was no sign of the organism. Creek flow here in terms of population was approximately the same as at Lincoln—roughly 2.5 second feet per 1,000 persons.

At Guadalupe raw sewage from the town and wastes from the Union Sugar Company, located at Betteravia, discharge to the Santa Maria River a mile or so from the ocean. Below the waste outlet the stream is a fresh water slough. *Sphaerotilus* growths are common in the stream below the outlet and also in a ditch which carries the wastes from the sugar plant.

The profuse growths of fungus, principally *Sphaerotilus*, in the Truckee River below the Crown Willamette Paper Company Plant at Floriston, California, led to a Federal injunction at the suit of the State of Nevada (7) because of the great damage to the water supply of Reno, about 25 miles below, and also because trout eggs were smothered and young trout were killed. Flow of the river in the driest months of the year was from 300 to 500 second feet. At the time the plant produced about 30 tons of sulphite wood pulp and 12 tons of ground wood pulp, yielding approximately 42 tons of paper per day. In this case the river looked like a stream of dilute dish water. Dissolved oxygen tests at the time showed approximately 70 per cent of saturation and relative stability was 97 per cent.

The Mokelumne River for twenty miles below Lodi was studied by the Bureau last winter in connection with the discharge of winery wastes to it. Three wineries in the vicinity of Lodi and Woodbridge discharge plant wastes and still slops to the slightly turbid river. During the

season of about 60 days, the three wineries crushed 21,600 tons of grapes, of which approximately one-third went to brandy production. From our studies the population equivalent of wastes from one ton of grapes seems to be about 33 persons, for wine making, and 225 in making brandy. The average daily flow of the combined wastes was estimated to be equivalent to the sewage of 30,000 persons. River flow was 400 to 600 second feet. Hence the dilution in terms of population was considerable—roughly, 17 second feet per 1,000 population. But likewise the growths in the streams were markedly less than in highly polluted streams. They were mainly confined to a narrow streak for a few hundred yards below each outlet, where the growths attached themselves to twigs and weeds and resembled sheeps'-tails waving in the water. The coarse growths then ceased, but even as far as 17 miles downstream, fragments of the organism clung to vegetation along the banks or floated with the water in quantities sufficient to impair the river for a water supply. Here, the *Sphaerotilus* growths act as indicators of organic pollution. A similar experience occurred in a small creek near Rutherford, a branch of the Napa River. As a result of the growths, the winery was required by the Fish and Game Commission to dispose of its wastes on land, due to harmful effects on fish. In Salmon Creek, in the vicinity of the town of Bodega, *Sphaerotilus* growths occurred below a creamery which discharged wastes to the stream.

Another striking case of stream pollution was Kings River, at Reedley, several years ago when two or three canneries discharged wastes to the river. They were handling around 100 to 150 tons of fruit per day, representing a population equivalent of perhaps 15,000 to 30,000 people. The river flow may have been 200 second feet—roughly, 6 to 12 second feet per 1,000 population. The water was sparkling clear, showing no signs of pollution, excepting the fungus growths. The fungus accretion on submerged twigs and branches of trees and water weeds grew to the size of a man's head for miles down stream. Gradually the clumps would disintegrate and float away.

The habits of growth and the influence of environment and food supply suggest several control measures. Even normal sewage evidently contains enough carbonaceous waste to support some *Sphaerotilus* if other conditions are right, but if there is reason to suspect some especially important source of carbonaceous matter which can be cut off, the worst of the growths may sometimes be eliminated. Any physical changes that deplete oxygen in the sewage, or make it strongly alkaline or acid, likewise strike at contributing factors. That is probably the reason that at Dunsmuir metering of the water system with the consequent reduction in water consumption has been followed by no further trouble with the fungus. The more concentrated sewage rapidly exhausts the oxygen.

This suggests the blocking of a sewer for a period to allow the disappearance of dissolved oxygen and establishment of septic conditions. Such an environment should kill the *Sphaerotilus* growths. It is reported that at Dunsmuir (8), liming of a clarifier affected by the growths seemed effective in its control. Here also hypochlorite of lime at a 2.25 p.p.m. dose fed into the sewer kept down the growth in the outfall. Two p.p.m. of copper sulphate fed into the sewer for three days is reported to have killed off the organism at Choteau, Montana. The sewer was first thoroughly flushed and cleaned, then each block of sewer was plugged and a "strong" copper sulphate solution was allowed to stand in contact with the growth for 15 to 20 minutes. Roseville also has used copper sulphate. Ruchhoft and Watkins (4) report that lime in doses of over 100 p.p.m., in activated sludge containing *Sphaerotilus*-like organisms, reduced the growths and a 500 p.p.m. dose dissolved them. Aeration up to 120 hours helped but did not completely eliminate them. At a pH of 6.3 or less they were killed.

The slimy growths here discussed cause difficulties in some communities seasonally; in others they may occur under special conditions. The experiences cited indicate no single cureall, but it is hoped this brief review may be of assistance where similar growths may occur in the future.

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DIGESTOR OVERFLOW LIQUOR—ITS CHARACTER AND EFFECT ON PLANT OPERATION*

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One of the most difficult problems facing operators of separate sludge-digestion plants is that relative to the disposal of the digestor overflow liquor. This problem has been accentuated in recent years because of the greatly increased number of activated sludge plants where combined raw and activated sludges are being digested, resulting in periodic plant upsets because of the return of the overflow liquor to the raw sewage.

Character of Overflow Liquor.—In considering overflow liquor in relation to its effect on plant operation we are mainly interested in its volume, total and settleable solids content, and its biochemical oxygen demand. Data obtained at a number of representative plants during the past three years are given in the accompanying table.

B.O.D. results were obtained at only a few of these plants but representative figures show a five-day demand ranging from 150 to 30,000 p.p.m., an average being about 250 p.p.m., where the total solids content does not exceed 0.30 per cent.

Unfortunately the analysis of digestor overflow is not a routine procedure at most plants so that some of the figures cited in this table are merely illustrative of conditions existing at the time the samples were analyzed and do not necessarily mean that the conditions indicated exist at the present time. It will be noted that the plants listed are divided into three groups: (1) plants where only raw sludge is digested; (2) plants digesting raw and trickling filter sludge; and (3) plants digesting raw and activated sludge.

In the first group, with the exception of two plants, overflow total solids are fairly uniform, averaging 0.25 per cent (omitting Fond du Lac and Sheboygan). The volume of overflow liquor per million gallons of sewage, however, varies within a wide range. This is due to excessive pumpage of sludge in a number of cases. The suspended solids vary from 500 to 4120 p.p.m. and the settleable solids from 0.20 to 31 c.c. per liter. Without any other disturbing factors present, it has been noted that the latter vary inversely with the volume of raw sludge introduced. Of greatest interest is the ratio of overflow solids to raw sludge solids pumped to the digestors. The tabulation shows that this varies from 2 to 64 per cent. This shows that the overflow liquor is a

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Analyses of Overflow Liquors from Sludge Digestion Tanks

Plant	Sewage Flow M.G.D.	Estimated Contributing Population	Sludge Pumped G.P.D.	Sludge Pumped Gal./M.G. Sewage	Dry Solids in Raw Sludge Added Lb./Day	Overflow Liquor			Lb. Overflow Solids per 100 Lb. Raw Sludge Solids
						Total Solids %	Suspended Solids %	Settleable Solids C.C./Lit.	
TANKS DIGESTING RAW SLUDGE ONLY									
Antigo, Wisc.	0.60	5,600	1,700	2,850	343	0.20	0.050	—	8.25
	0.59	5,600	3,150	5,350	1,270?	0.24	0.130	18.5	4.98
Aurora, Ill.	5.76	43,000	6,670	1,160	3,500	0.20	0.080	11.0	3.17
Birmingham, Ala.	6.50	100,000	20,000	3,080	9,560	0.43	—	—	7.50
Easton, Pa.	1.25	20,000	8,400	6,720	1,540	0.23	0.189	0.30	10.45
Fond du Lac, Wisc.	2.00	21,000	4,200	2,100	1,400	0.80	0.200	24.0	20.00
Grand Rapids, Mich.	21.00	160,000	56,680	2,700	15,650	0.35	0.183	13.6	10.58
Hartford, Wisc.	0.212	2,770	1,230	5,750	264	0.272	0.094	—	10.56
Kiel, Wisc.	0.115	1,040	800	6,950	56	0.54	0.203	—	64.20
Northampton, Pa.	0.24	3,200	2,400	10,000	290	0.19	0.159	0.20	13.08
Petoskey, Mich.	0.60	6,000	2,700	4,500	562	0.20	0.121	25.0	8.00
Red Bank, N. J.	0.75	11,000	14,400	19,200	1,460	0.19	0.063	low	15.6
Sheboygan, Wisc.	0.25	1,500	4,800	19,200	1,880	0.78	0.412	—	16.6
Springfield, Mo.	3.50	35,000	4,250	1,210	1,750	0.10	—	31.0	2.02
Sturgis, Mich.	0.50	6,000	7,200	14,400	540	0.26	0.141	29.0	28.9
San Antonio, Tex.	14.35	200,000	37,600	2,620	12,700	0.134	0.098	—	3.31

Analyses of Overflow Liquors from Sludge Digestion Tanks—Continued

Plant	Sewage Flow M.G.D.	Estimated Contributing Population	Sludge Pumped G.P.D.	Sludge Pumped Gal./M.G. Sewage	Dry Solids in Raw Sludge Added Lb./Day	Overflow Liquor			Lb. Overflow Solids per 100 Lb. Raw Sludge Solids
						Total Solids %	Suspended Solids %	Settleable Solids C.C./Lit.	
TANKS DIGESTING RAW AND TRICKLING FILTER SLUDGE									
DeKalb, Ill.	0.915	16,000	3,770	4,120	2,310	1.00	0.580	28.0	13.6
Freehold, N. J.	0.32	6,300	2,700	8,430	615	1.23	—	155.0	45.0
Waukesha, Wisc.	1.73	12,500	14,500	8,380	1,440	0.40	—	34.0	33.6
TANKS DIGESTING RAW AND ACTIVATED SLUDGE									
Muskegon Hts., Mich.	0.75	10,000	7,350	9,800	1,310	1.24	1.08	750.0	58.0
Newark, N. Y.	0.75	7,000	1,660	2,210	1,185	0.27	0.72	29.0	3.15
			5,000	6,670		2.57	—	950.0	90.5
Peoria, Ill.	10.50	110,000	50,000	4,770	19,600	0.81	0.65		17.25
						0.20	0.058	—	4.26
Phoenix, Ariz.	8.68	70,000	38,900	4,480	8,560	0.20	0.097	—	7.58
Salem, Ohio	1.00	10,000	1,500	1,500	1,180	0.260	0.113	27.6	2.75
						2.00	—	—	21.2

major factor to be considered in digestion and that it should always be taken into consideration in calculating a digestor solids balance and also the degree and time of digestion.

In the second group, the effect of the secondary sludge added is reflected in an increase in the overflow total solids, while a still greater effect is noted in the third group due to the presence of activated sludge. As in the case where only raw sludge is digested, the volume of suspended and settleable solids of the overflow and the ratio of overflow solids to raw sludge varies greatly in these two groups, by far the greater variations and more serious conditions occurring in the cases where activated sludge is present.

Factors Influencing Character of Overflow.—Known factors that influence the volume and character of the overflow liquor are:

1. Character of sewage solids digested
2. Type of sludge digested
3. Moisture of sludge pumped to digestor
4. Digestion period
5. Degree of agitation (including rate of gas production per unit of tank surface area)
6. Temperature of digestion
7. Digestor design
8. Convection currents

The more important of these are discussed below:

Effect of Character of Sewage Solids.—The total solids in the overflow increase with the fineness of division of the suspended solids removed in the plant, and with increased volatile matter content of the raw sludge. As the primary purpose of the disposal plant is to remove the maximum amount of solids in the sewage, this factor may be considered as uncontrollable as far as the digestion operation is concerned.

Effect of Type of Sludge Digested.—As has been pointed out before, the addition of secondary sludge from trickling filters, or activated sludge, to a digestor considerably increases the overflow solids. This is due both to the increased percentage of fine solids and to the nature of secondary or activated sludges, which fail to thicken except after long periods of digestion.

In a few cases lagooning of activated sludge has been resorted to because of the difficulty of handling it by digestion. These troubles have been due more to the difficulty of thickening the waste activated sludge, however, than to lack of digestion of the solids. The tendency is now toward furnishing greater digestion capacities where secondary treatment is provided. It appears that at least 3.0 cu. ft. per capita is required where activated sludge is digested by a single-stage process, assuming that the activated sludge is suitably thickened before digestion.

Effect of Moisture of Sludge Pumped to Digestor.—Excessive pumping of sludge greatly increases the amount of overflow liquor to be handled. Reduction in volume may be accomplished by concentrating the raw or mixed sludge in the primary settling tank or by pumping the sludge to a separate thickener or decanting tank before allowing it to enter the digestor.

The former method is in use at most activated sludge plants where aeration is preceded by sedimentation. Return of the waste activated sludge to the primary tank materially reduces the volume of sludge to be handled. At Salem, Ohio,[1] a 2 ft. blanket of sludge was built up in the primary clarifier so as to secure an average mixed sludge moisture of 90 per cent. At Newark, N. Y., a similar procedure was followed and a 92 per cent moisture sludge was obtained. Haseltine[2] points out that difficulties may be encountered in this procedure due to a separation of the coarser solids in the waste sludge and a return of the fines to the aerators resulting in sludge bulking and an increase in the air requirements. Such a condition may easily occur, especially during warm weather and where the wasting of activated sludge is not properly controlled. Operating results indicate that a two-hour primary sedimentation period is required to satisfactorily re-settle waste activated sludge and that the sludge should be wasted at a low rate, continuously if possible. According to Haseltine[2] extra depth should be provided to retain a sludge blanket of 1 to 3 feet.

The disadvantage of this method, aside from a possible reduction in settling efficiency of the primary clarifier, is that septic action may occur before the sludge thickens. Such a condition occurred at San Antonio, Texas, and Phoenix, Arizona.

In the pumping of raw or mixed sludges from a primary clarifier, time-clock operation of pumps has been successfully employed. Such an arrangement may be used to pump sludge automatically for any predetermined period, at any time interval, as is done at Birmingham, Alabama. The effect of the time-clock operation is to produce the thickest sludge possible and so reduce the volume of sludge and the corresponding volume of overflow liquor.

At Los Angeles, Goudey and Bennett[3] showed that waste activated sludge may be thickened in a separate tank and that if a small amount of chlorine be added to the thickener, septic action may be prevented even under severe climatic conditions. At Phoenix, Arizona, Travaini[4] has operated a similar type of unit under various conditions, thickening raw, mixed and activated sludge for extended periods. The most satisfactory practice is to waste mixed liquor to the thickener. Forty pounds of chlorine are added to the thickener per day to prevent septic action. This operation results in the production of a 95 per cent moisture ac-

tivated sludge, which is pumped to the digestor along with the raw sludge. The digestor overflow is low in solids and is returned to the raw sewage without trouble. The thickener overflow, as at Los Angeles, is sparkling clear and is discharged into the plant effluent.

Decanting tanks operated on a fill-and-draw principle have been used at Phoenix, Los Angeles and Yosemite National Park, with some limited success. Their greatest handicap is odor trouble due to the accumulation of septic sludge in the decanters.

Effect of Digestion Period.—Increased rate of digestion, no matter how accomplished, increases the solids in the overflow. This is due primarily to the increased rate of gas production, which in turn carries sludge particles to the surface of the tank. From the standpoint of the overflow liquor only, it is not desirable to cause digestion to proceed at too high a rate unless some provision is made to separately treat the overflow liquor. No known methods of speeding up digestion, with the possible exception of continuous violent agitation and thermophilic digestion disturb the supernatant liquor usually present in a digestor enough to cause a large increase in the overflow solids.

Effect of Degree of Agitation.—Violent agitation, if carried out continuously or when sludge is pumped to the digestor, causes increased overflow solids due to a purely mechanical action. In this respect, we may consider high gas ebullition per unit of tank surface area. Actual plant results show that less surface disturbances may be expected in shallow tanks of large surface area. Also, disturbances such as are caused by pumping raw sludge at too high a rate or over too long a period cause high overflow solids. Tests at Aurora have shown that peak gas production and maximum tank disturbance occur almost immediately after raw sludge is introduced, the maximum gas rates being about 2.5 times the average.

Effect of Digestion Temperature.—Increased temperatures increase the rate of digestion, and therefore cause an increased solids content of the overflow. In the ordinary digestion range from 70° to 95° F. no appreciable effect is noted unless, however, the temperature is suddenly raised from a lower temperature. Unheated tanks, in which rapid digestion starts when the temperature increases after the winter months, show high overflow solids and often a complete overturning of the tank contents.

At Aurora, Ill., large-scale tests on thermophilic digestion as compared with digestion at 90° F. showed that at the higher temperature range the overflow liquor was very high in colloidal solids which were hard to handle. Comparative results were as follows:

	130° F.	90° F.
Total Solids per cent	0.309	0.231
Volatile Solids per cent	67.1	58.5
Settleable Solids—C.C./Liter	17.2	12.0
Suspended Solids, P.P.M.	1490	773
Non-settleable Suspended Solids, P.P.M.	451	107

Effect of Digestor Design.—Except for provision of an adequate supernatant liquor zone there are no practical design features of a single-stage digestor that will improve the quality of the overflow. It can be greatly improved, however, by the use of two-stage digestion. In this method, digested sludge from the bottom of one digestor is pumped or drawn to another digestor or storage tank before final disposal on filters or sand beds. The Peoria, Ill., plant is a good example of this type of installation, which is particularly adaptable to activated sludge digestion. Kraus [5] reports that mixed raw and activated sludge are pumped to primary digestors, an equal volume of digested sludge being drawn from the bottom of these units into secondary tanks. No overflow liquor is taken from the primary tanks unless it is clear. The sludge in the secondary tanks concentrates rapidly, leaving a clear supernatant liquor of very low suspended solids content. One of the difficulties with this type of operation is that the digested sludge in the primary units may be depleted, causing acid conditions. At Newark, N. Y., where stage digestion was tried out experimentally for a period of one year, the possibility of such an occurrence was obviated by providing vigorous stirring in the first stage so that the solids content in the digestor would be uniform throughout. The bottom sludge from the first stage was displaced automatically to the second stage when raw sludge was pumped. Excellent results were obtained both as regards gas production and quality of the overflow liquor. Reasons for a better type of overflow from a two-stage system are:

1. That most of the gas is obtained in the first stage thus reducing the agitation in the second stage to a minimum;
2. That short-circuiting of raw or partially digested sludge to the overflow is reduced to a minimum; and
3. That the more completely digested the sludge, the clearer is the supernatant liquor obtained.

Methods of Disposing of Overflow Liquor and Their Effect on Plant Operation.—Methods of eliminating, treating or disposing of overflow liquor that have been proposed or are in use are:

1. Elimination of overflow by discharging to drying beds or filters a volume of digested sludge equal to the volume of raw sludge introduced.

2. Treatment by chemicals.
3. Treatment by storage.
4. Disposal on sand beds.
5. Return to raw sewage.

Elimination of Overflow.—This method was in use at the Los Angeles experimental plant. It was claimed that this did not interfere with the drying rate on sand beds as this was a function of dry solids loading per unit of area. On vacuum filters, however, the thinner sludge produced reduced the filter rate considerably. It has been brought out that this scheme might fail due to the depletion of "seed" sludge in the tank. With activated sludge digestion this is unlikely, especially with short digestion periods. In any case, rapid agitation could be used to prevent segregation, as has been done in stage digestion.

Treatment by Chemicals.—The use of lime and ferric chloride has been reported as beneficial in clarifying overflow liquor. The writer's own experience in this regard is that from a practical standpoint these chemicals are of little value. Lime may even cause difficulty by producing a more voluminous sludge and ferric chloride will more often cause flotation of the solids instead of sedimentation.

Chlorine is said to be of value in treating overflow liquor before its return to raw sewage. Beyer [6] brought this point out at the last meeting of the California Sewage Works Association. More recently, Rankin found that at Birmingham, Alabama, 300 to 400 p.p.m. of chlorine was sufficient to sterilize the overflow and cause the solids to settle out rapidly.

Treatment by Storage.—The use of settling tanks for reducing the suspended solids in the overflow is applicable to most plants, especially where only primary sludge is digested. The mechanism of this process is that the finely divided suspended solids held in suspension by the disturbance in the digestor, due to gas ebullition, settle readily in a quiescent zone substantially free from gas. This idea is in use at Newark, N. Y., where a gasometer tank is used as the settler. This has an added advantage in that freezing of the gasometer is prevented during the winter months.

In some cases, however, especially where activated sludge is digested, the solids will not settle out even after long settling periods and such settling tanks are useless.

Disposal on Sand Beds.—Provisions for handling overflow liquor on sand beds are installed at a number of plants such as Salem, Ohio, and Muskegon Heights, Michigan. This method is, on the whole, unsatisfactory for year-round operation, chiefly because of cost and liability of odor nuisances. It is, however, a very good temporary expedient when no other known method will work.

Return to Raw Sewage.—This method of operation is practiced at practically all plants where only raw sludge is digested. This should cause no trouble where the total solids do not exceed 0.30 to 0.50 per cent and where the sludge pumping is kept down to a minimum. Van Kleek [7] states that this volume is generally 0.1 to 0.4 per cent of the total sewage. Under these conditions, the effect on the plant effluent will be negligible, especially as a large part of the suspended solids settle readily in the settling tank. As a matter of fact, in the average small plant where the raw sludge is pumped at 96 per cent moisture, what may be considered as a satisfactory overflow will increase the effluent solids by only 1 per cent and the B.O.D. by less than 0.5 per cent.

Precautions that should be taken in returning the overflow are to mix it thoroughly with the raw sewage and to introduce it through a submerged inlet so as to prevent aerial nuisances.

Where the overflow solids exceed 0.3 per cent, as frequently happens in the operation of activated sludge plants, this procedure may lead to considerable difficulty. Although a major part of the settleable solids will be removed in the primary clarifier, a circulating load may eventually be built up and the aerator influent will be fouled to such an extent that sludge bulking may result. In such cases it is necessary to run the overflow to sand beds until the primary system is free of sludge. There are, of course, cases where no amount of regulation will clear up the overflow and year-round disposal on sand beds is required. Such cases are rare and in many cases may be corrected, ninety per cent of the troubles being traceable to excessive sludge pumping.

Summary

Experience in handling overflow liquor indicates that the quality of the overflow is to a large extent controlled by the character of the sewage solids and the type of sludge digested.

The best method of disposal is to return the overflow to the raw sewage. This may be accomplished without any operating difficulty when the total solids do not exceed 0.3 per cent chlorination prior to return to the raw sewage is of advantage, especially when the overflow causes septic action in the settling unit.

Where the total solids in the overflow exceed 0.5 per cent, disposal on sand beds is recommended.

The most practical methods of reducing or minimizing the effect of overflow liquor are to reduce raw sludge pumping to a minimum and to resort to two-stage digestion.

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DISCUSSION

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The very thorough discussion of digestor overflow liquor by Dr. Fischer is most interesting. Much has been said on the subject during recent years when separate sludge digestion came into general use. There are few analytical data, however, on the actual character of this liquor. The data given in Dr. Fischer's paper are a valuable addition to the knowledge of the art. These results should be of value in demonstrating that the supernatant liquor may not be as bad as generally supposed. There seems to be a common belief that this liquor is most harmful and poisonous. When added to the sewage flow at a high rate, plant operation may naturally be upset. This would occur when liquor is displaced by pumping fresh solids into the digestion tank. The writer has held the belief for some time and has previously stated † that a proper and suitable disposition of supernatant liquor is to return it to the sewage flow, and is glad that Dr. Fischer mentions this as a preferred method. An ideal method is to return the liquor at a slow uniform rate. This has been done by allowing the gas to force out the liquor at a rate equal to or less than the rate of gas formation. By this procedure the percentage of liquid added to the raw sewage is very small and as the tank contents are not stirred up by pumping, the solid content of the displaced liquor is low. The writer even believes that, properly handled, the liquor is helpful rather than harmful when returned to the activated sludge process, preceded by preliminary sedimentation. This opinion is based on observation and while the writer has no adequate scientific data to support it, he knows of no results that disprove it.

* With Clyde Potts, Consulting Engineer, N. Y. C.

† Notes on Sludge Digestion, THIS JOURNAL, **3**, 475 (July, 1931). Gas Collection from the Digester of Activated Sludge at Rockville Centre, N. Y., THIS JOURNAL, **3** (October, 1931). Sludge Digestion and Gas Collection, THIS JOURNAL, **4** (March, 1932).

THE TRICKLING FILTER FLY (PSYCHODA ALTERNATA), ITS HABITS AND CONTROL *

By Gordon M. Fair

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The *Psychodae*, or moth-like flies, are cosmopolitan in their distribution. They are found throughout the North American continent and are not restricted to trickling filters. They abound in the fields and woods and in cities, and may be observed wherever the female fly can deposit her eggs upon material, notably moist decaying organic matter, that will serve as food for the larvae.

There are numerous species of *Psychoda*. Some are completely aquatic, others semi-aquatic. To the latter group belong the several species that breed in trickling filters. These have come to be known as "the trickling filter fly." The most important species that has its habitat in trickling filters is *Psychoda alternata* Say, which is found in the English and German literature also under the name *Psychoda sexpunctata* Curtis.[5] Other species reported as occurring in trickling filters are *Psychoda cinerea* (sometimes *cinera*) Banks [7] and *Psychoda phalaenoides* Linnaeus.[4, 5]

Psychoda alternata is readily recognized in the adult stage by the mottled appearance of the wings (Figure 1) due to a denser growth of hairs at certain peripheral points (6 or more) along the veins. As the name indicates, *Psychoda cinerea* is browner in color than *Psychoda alternata*.

In order to appreciate the factors underlying the successful control of *Psychoda* or trickling filters it is essential to have a clear picture of the life history and morphology of this fly.

Life History and Morphology

The morphology of the larva and pupa is shown in Figure 1; their mode of existence in trickling filter slime is indicated in Figure 2. The characteristics of the insect in its various developmental stages in trickling filters may be summarized as follows.

Egg.—The female fly lays her eggs on the film covering the trickling filter ballast. These eggs resemble small grains of rice, 0.2 to 1 mm. in length.[4-7] They are generally deposited in gelatinous irregular masses

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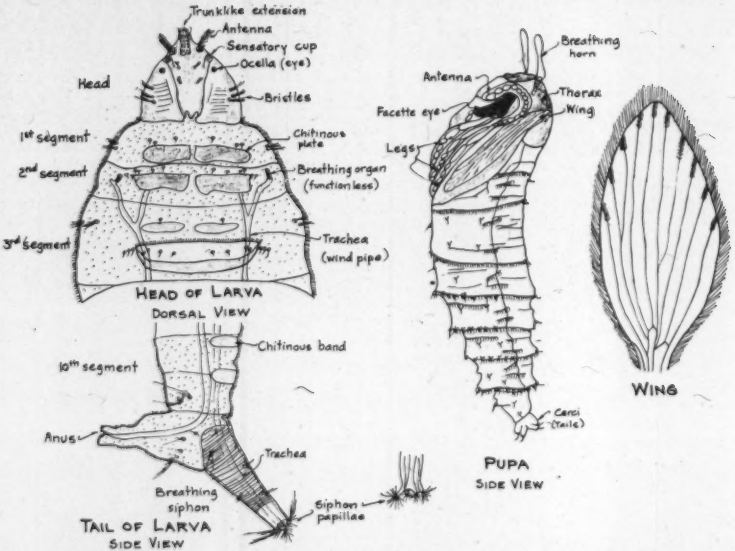

FIG. 1.—Morphology of the filter fly, *Psychoda alternata*. (After Zuelzer.)

containing 15 to 40 eggs. Single eggs and masses of 100 eggs have also been observed. With exception of the yolk, the eggs are almost transparent. At 70° F. the eggs hatch in less than two days.[7] They can probably withstand submergence and winter conditions.[7]

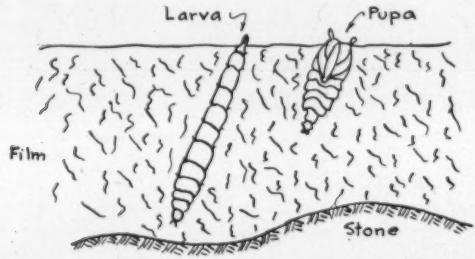

FIG. 2.—Position of larva and pupa of *Psychoda* in trickling filter slime.

Larva.—The larvae resemble mosquito wrigglers. They are white in color and possess a distinct head with a well-developed biting mouth, eyes and feelers. The larval body is composed of eleven segments. The eleventh or posterior segment carries the anal papilla and a breathing tube or siphon with two breathing openings. These can be protected by being covered with four papillae or nipples. There are two further breathing openings (or tracheal tubes) in the second segment on the back of the larva; apparently they are functionless. Two main tracheal stems run dorsally through the larva and send out a large number of branches in each segment. These supply the larva with oxygen. The alimentary tract passes almost straight from mouth to anus.

The larva moults three to five times, the last moulting producing the pupa. By voracious feeding, the larva grows in length from ¾ to over 9 mm. Soon after hatching the young larva makes its way into the film surrounding the filter medium. Legless, it moves like a caterpillar. If the filter slime is heavy enough, the larva pushes itself head-first into the film and usually permits only its breathing tubes to protrude at the surface. At times the larva may be totally covered by the film in which it is feeding, and move to the surface only at intervals for breathing.[3] Apparently the larva is omnivorous. While it feeds chiefly on decaying organic matter, it ingests also molds, algae and protozoa.

The larval stage is probably the longest life stage. In northern climates the insect is believed to hibernate chiefly in this stage and in the egg stage.[3, 7] At 70° F. the larval stage occupies 9 to 15 days;[7] at 60° F. 24 days, at 85° F. only 8 days.[6] Ordinarily the larva suffo-

cates when totally submerged in water for 24 hours.[7, 8] The breathing tube sometimes entraps a bubble of air, however, and the larva has then been known to resist 48 hours of submergence.[6]

Pupa.—The pupa is yellowish in color and is shorter (6 mm.) and thicker (3½ mm.) than the larva. All organs of the perfect insect are fully developed in the pupa but are held rigidly against the body. The pupa breathes through two horns attached to the thorax. These breathing horns protrude through the filter slime in which the pupa rests. There is no abdominal breathing. The pupa moves by abdominal motions and can ascend or descend in water.[3]

The pupa does not feed. At 70° F. the adult fly emerges after 20 to 48 hours, and the pupal stage seldom occupies more than a few days.[3, 7] Hibernation of pupae has been reported.[7]

Imago.—After emergence, the perfect insect runs to a dry spot and the wings unfold. Males emerge before females and live only a few days. Females have been observed to live seven days at normal temperatures, but only when they have not copulated and retain their eggs.[6] Hibernation of adult flies in the lower strata of trickling filters, but not in the open, is mentioned by Zuelzer.[3]

The adult fly moves upward and towards the light after emergence. It thus escapes from the filter. Copulation takes place while the insects are at rest and has been observed as early as 40 minutes after emergence.[6] Most observers claim that the adult does not feed, but Turner[6] states that he has never failed to find in the alimentary tract of the fly some of the liquid of the slime on which it was reared. In trickling filters, the adult fly likes to rest on the dry under-surface of the top layers of stone[4] or in sheltered places about the filter.

The adult flies are sluggish and move chiefly by hopping running and short flights. Wings and body are covered with hairs which give the insect its moth-like (*psychoda*) appearance. This hair covering offers resistance to flight and restricts the voluntary radius of flight. Wind, however, may carry the flies appreciable distances from the filters. Distances of 1000 feet to almost a mile are mentioned in the literature.[7, 17] The flies are so small as to pass through all ordinary sizes of screen cloth, unless the screening is impregnated with a substance such as tanglefoot.[7] Males measure 2.5 to 3 mm., females 4 to 4.5 mm. This difference in size may account for some reports that two species have been observed on a filter.

Length of Life Cycle.—The following length of life cycle for *Psychoda alternata* seems to represent the generalized experience of observers:

Temperature—° F.	Days	Temperature—° F.	Days
85	7	70	16
80	10	65	19
75	13	60	22

Prevalence in Trickling Filters

There is a seasonal variation in the prevalence of trickling filter flies, a vertical variation in the larval infestation of filters, and a variation in prevalence at different sewage works.

Estimating Prevalence.—Three methods of estimating the prevalence of *Psychoda* have been employed.

1. Recording daily catch of adult flies on fly-paper exposed above the ground on the four sides of a filter.
2. Counting the larvae and pupae on a given number of stones taken from a certain depth.
3. Counting the larvae and pupae in composite samples of the effluent.

The first of these methods is unreliable, chiefly because of variations in weather conditions and their effects upon the flight of the flies and their emergence from the filter. The second appears to be the most satisfactory. It must be realized, however, that the center of population shifts in depth from time to time. Account must also be taken of the size of the stones or ballast examined; an estimate of surface area might well be made and a number of different sampling depths employed. The third method is of value only in measuring the relative effect of larval destruction by certain control methods such as chlorination and flooding. It does not tell much about the degree of infestation before or after attempts to control fly breeding.

Seasonal Variation.—The seasonal variation in fly breeding is associated chiefly with prevailing temperatures and the thickness of film on the filter ballast. As a rule, the flies emerge from the filters in great numbers during the first warm days of spring prior to the vernal unloading of the beds. Following the latter, they disappear to an appreciable extent until the summer film has built up on the stone. Increasing gradually in number, a peak is reached in late summer after which a recession of breeding is observed. In the northern United States breeding has been noted as late as December.[8]

Elevated temperatures shorten the life cycle of the fly and thus increase the rate of breeding and maturing. The building-up of organic slime on the filter ballast furnishes food and shelter for voracious larvae.

Vertical Variation.—Larvae and pupae are found throughout the depth of trickling filters. They occur in greatest concentration, however, in the zone 3 to 12 inches from the surface.[7, 14]

Variation at Different Works.—There is an appreciable variation in fly nuisance at different treatment works. This is due chiefly to structural differences in the filter beds and to variations in methods of plant operation. Two structural conditions seem to favor fly breeding: (1) Construction of filters with open walls and (2) use of surface ballast of

large size. Both of these afford moist cavities where the mature insect can emerge from the pupa and where eggs can be laid without exposing the fly to currents of liquid which will drown it or wash it away.

As to differences in operation, deposition of excessive amounts of solids in the bed due to poor preliminary removal of suspended matter or to choking of the surface layer by fungal growths, will encourage fly development. A very badly clogged filter, on the other hand, may so restrict passageways and so reduce dry surfaces in the filter that oviposition and fly emergence are rendered difficult. Fly breeding will then drop off. It seems, therefore, that both a seriously clogged filter on which ponding is frequently observed, and a relatively clean filter, may show quite low fly infestation. Bio-flocculation, *i.e.*, partial activated-sludge treatment prior to filtration, is said to have reduced fly breeding at Birmingham, England, because the applied sewage contains little sludge-forming material. At Columbus, Ohio, high dosage has been reported to have induced more or less continuous unloading of humus and to have decreased fly infestation.

Hygienic Considerations

Psychoda is not a biting fly. The skin irritation that it is reported to cause in some individuals may possibly be due to the hairs of the fly entering the pores of the skin [4, 5] or to some idiosynerasy of the person affected. A few tests by Wilson and Johnson [4, 5] in which they placed macerated flies on neutral-red-bile-salt lactose agar or allowed them to walk over this medium, gave no evidence that the flies could carry infection mechanically. In view of Turner's [6] findings and other circumstantial sanitary evidence, however, it would seem advisable to continue to regard *Psychoda* as a potential menace to health as well as an aërial nuisance.

Control of Psychoda

A number of different ways have been suggested or are in use for controlling or preventing the development of *Psychoda* in trickling filters. These may be classified as follows:

A. Biological control.
  1. By natural enemies of *Psychoda.*
     a. Birds and predatory flies.
     b. Spiders and mites.
     c. Parasites.
  2. By animals that compete for the food of *Psychoda.*
     a. Water springtails (*Achorutes viaticus*).
     b. Spiders and mites.
     c. Snails, leeches and worms.

B. Chemical control.
1. By repellents.
2. By contact insecticides.
3. By film-destroying compounds.

C. Physical control.
1. By burning.
2. By flooding.
3. By drying.
4. By surface barriers and tight walls.
5. By glass-overs or other covers.

Biological Control

While swallows and wagtails are known to feed upon *Psychoda*,[4, 5] the flies are so small that they are probably not relished sufficiently by birds to make possible their control by this means. Certain predaceous flies are also reported [4, 5] "as killing, in a frenzied manner, large numbers of Psychoda"; but there is probably no consistent activity of these insects. Wilson and Johnson [4, 5] state that the presence of masses of fungal hyphae in the dead bodies of the filter fly suggests the possibility of fungal attacks, such as are known to occur in the ordinary house fly.

Spiders and Mites.—The belief has been expressed [11] that "red spiders" control the development of *Psychoda* by destroying larvae and adult flies. The occurrence of spiders has been noted at many plants [10, 11, 22] often in great numbers, but operators have generally not associated their development with variation in fly life. Collections of filter life made by the author at Fitchburg, Mass., have proved to contain mites as well as spiders. The mites were red in color and about 1 mm. long. They have been identified as a species of *Parasitus*. The red spiders varied in size from 3 to 5 mm. and have been identified as a species of *Grammonota*. Both insects are predaceous. The spiders may feed on the adult flies, but it is doubtful that they kill the maggots. The mites may feed on small maggots but would probably be of little value in controlling the number of flies.

Besides these possibly direct enemies, there are indirect checks to the development of *Psychoda* in the form of snails, leeches, and worms, as well as other insects, such as water springtails. Many of these organisms develop in trickling filters because they have much the same food habits as *Psychoda* or find other suitable pabulum in the filters. While competition for food among the various denizens of trickling filters probably results in a certain measure of fly control, food material is commonly so abundant that it will support a large and varied animal population including sufficient *Psychoda* to create a fly nuisance.

Water Springtails.—Among the different organisms frequently recognized on sprinkling filters, the water springtail, *Achorutes viaticus* (Linnaeus) Tullberg (Figure 3), has attracted much attention in con-

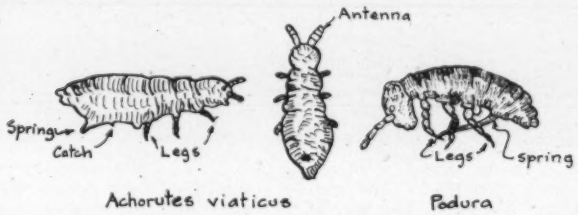

FIG. 3.—Morphology of the water springtail, *Achorutes viaticus*.

nection with *Psychoda* control. For this reason a somewhat extensive description of this insect may not be out of place. *Achorutes* is a small wingless insect, a member of the family *Poduridae*. It is blue-black in color and about 2 mm. long.[4, 5] *Achorutes* hatches as a complete insect from whitish, nearly globular eggs, 0.2 to 0.25 mm. in diameter, that are laid singly or in clusters of 15 or more in the top few inches of the filter ballast. The insect can walk a few hours after birth and crawls about on moist surfaces or pools of water or sewage. Sometimes it jumps several inches by releasing a catch that holds a springing mechanism on its abdomen. *Achorutes*, however, is not so active a jumper as some *Poduridae*. Hence its name *Achorutes* (not dancing). For comparison the black water springtail (*Pódura*) is shown in Figure 3 together with *Achorutes*. The insect is never wetted even when resting on the water surface.

Like *Psychoda*, *Achorutes* is cosmopolitan in its distribution. It can readily be colonized on trickling filters [12, 13, 14] and frequently establishes itself naturally. The water springtail may become as prevalent as the filter fly but it seems that the two insects seldom appear together in profusion. Maximum hatching of the water springtail takes place in June and August, and it may develop in numbers so large as to impart a purple color to the stones that it covers. It is most numerous from 3 to 6 inches below the surface of trickling filters.[14, 16]

The *Poduridae* are herbiverous. *Achorutes* itself is reported by competent authorities [4, 5] to be a scavenger that lives upon vegetable matter, perhaps animal matter, fungi and algae. The oft-repeated statement which has crept into the literature, namely, that "*Achorutes* are known to feed on the larvae of *Psychoda*" appears to be unfounded. It probably has its origin in the observation that the two insects generally do

not occur in large numbers on the same filter. The water springtail, unlike the filter fly, prefers situations where the sewage is ponding. Water surfaces are its natural habitat and ponding is frequently associated with the development on the filter surface of green algae which are the principal or preferred food of the insect. *Psychoda* is seldom associated with *Achorutes* in profusion (1) in ponded filters, because ponding implies surface clogging of sufficient intensity to interfere with the movement of adult flies into and out of the filter, and (2) in clean filters, because there is possibly active competition for food between the two insects and because the prevalence of *Achorutes* in the top layers of stone may force the flies to penetrate deeper into the bed with increased hazard to themselves.

While *Achorutes* likes ponded filters, it may itself remedy or prevent pooling by destroying the surface slime.

On the whole, therefore, it seems that there is little hope of securing adequate control of *Psychoda* by biological means. A certain degree of biological checking of fly development undoubtedly exists. There seems to be no known biological agency, however, that can be relied upon to prevent fly infestation of trickling filters.

Chemical Control

A great variety of substances has been studied by different workers in attempts to control *Psychoda* on trickling filters. Direct attack of the flies has been tested by using two broad groups of chemicals: repellents and contact insecticides. Of these, the first has for its aim the control of breeding by keeping mature flies away from the filters, while the second may essay the destruction of *Psychoda* either in the adult or in the developmental stages, or both. The most successful use of contact insecticides would naturally be promised by destruction of the fly before emergence. To accomplish this, the insecticide must penetrate to the larvae, pupae or eggs in the filter. Since the larval stage occupies the longest period of time in the life cycle of the fly, destruction of the larva should be most productive of control. A specific, or selective, contact insecticide would destroy the fly without injuring the biological film on the stones. This film is still regarded to be the active purifying agency in the treatment of sewage on trickling filters. The effect of contact insecticides on the film must, therefore, be considered along with its effect on the fly. The larva is imbedded in the film and can withdraw its breathing tubes from the film surfaces, providing it becomes aware of the insecticide before it is permanently injured. To be specific, therefore, the chemical would have to penetrate the film and reach the imbedded larva or, otherwise, render the film toxic in order to destroy the fly. It is hard to conceive of a chemical that would accomplish this task without to a considerable extent destroying the film itself.

Repellents.—The use of repellent chemicals has been studied by Peterson [14] in laboratory and field. Working with 52 substances, mostly volatile, including benzene compounds, essential oils, "Flit" and miscellaneous organic chemicals, no noticeable effect upon the flies was produced in the open air, although the odor of the essential oils and some of the other substances could be detected over appreciable distances. Contact with the repellent, however, was lethal.

Contact Insecticides.—Among the many chemicals studied by different workers in their effects on the trickling filter fly are the following: arsenates; [28] benzene [14] and benzene compounds, including bromobenzene,[14] chlorobenzene,[14] and diclorobenzene (ortho-,[14, 17–19, 23, 28] meta-[14] and para-[14]); borax; [7, 28] carbon bisulphide; [7, 14, 28] carbon tetrachloride; [14] chlorine; [7, 14, 17–20, 23–25, 28] copper sulphate; [7, 28] creosote; [21, 26, 27] ferrous sulphate; [7] "Flit"; [14] hellebore; [7] kerosene; [14, 17, 19, 23, 28] alone and mixed with orthodichlorobenze [18, 19] or with pyrethrum; [28] nicotine sulphate; [7, 28] pyrethrum; [28] phenol [14] and stone lime.[7]

The general conclusion to be drawn from the studies that have been reported is that there are numerous contact insecticides that will destroy *Psychoda* both in the adult and developmental stages. When applied to trickling filter beds, however, all of them are apparently non-specific or non-selective, destroying the film to some extent as well as the flies.

Ortho-dichlorobenzene and kerosene, mixtures of these substances or of kerosene and pyrethrum have been employed successfully in destroying adult flies in the open around trickling filters or in covered filters. "Flit" and other compounds can apparently also be used for this purpose.

All of the contact insecticides used for the destruction of fly larvae, except chlorine and creosote, are reported by experimenters as too expensive for use. Continuous chlorination for fly control apparently is costly and may reduce filter efficiency. Intermittent chlorination, in doses sufficient to carry an appreciable residual (3–5 p.p.m.) into the filters at weekly intervals during the height of the breeding season, has given satisfaction although failing in some instances. Intermittent application of an emulsion of creosote is reported from England [21, 26, 27] as rendering the filter slime unpalatable or otherwise objectionable to fly larvae over protracted periods of time. With this possible exception, however, it seems that the effectiveness of contact insecticide is due in large measure to film destruction and removal. Film thickness is apparently reduced below the optimum, if not the minimum, of larval requirements, and larvae enmeshed in sloughing film are carried away in the filter effluent. Unloading is induced artificially. Falling into the season of greatest filter activity, it is probable that the deleterious ef-

fects of film destruction are readily overcome and that filter efficiency as a whole is not greatly affected. It seems, furthermore, that a very thin film will accomplish as much work as a thick one. Studies at Harvard of the biochemical oxygen demand of sludge films have shown that the oxygen used up in a unit of time appears to be independent of film depth, provided anaerobic decomposition which takes place beneath the surface of thick films does not become so violent as to disrupt the film and expose the lower layers to oxidation.

Desirable effects incident to chlorination are the clearing and cleaning of distribution pipes and nozzles, and the maintenance of the surface in a cleanly state, and elimination of pooling.

It appears, in general, that contact insecticides will kill other forms of life on trickling-filter films as well as the larvae of *Psychoda*.

At Bradford, England, total absence of flies has been reported when the sewage is acidified with sulphuric acid to pH 3 to 4. Flies are present at pH 5 to 6, although not numerous.

Experience with chemical control agents seems to have established the value of kerosene and ortho-dichlorobenzene as well as mixtures of these substances or of kerosene and pyrethrum, for the destruction of adult flies. Substantial destruction of fly larvae appears to have been accomplished by chlorination, the benefits seemingly being caused largely by non-seasonal unloading of filter slime. The use of creosote is favorably reported, as is high acidity of the applied sewage.

Physical Control

As shown in the outline of control methods, five possible means may be considered for the control of *Psychoda*, namely: burning, flooding, drying, use of surface barriers and tight walls, and construction of glass-overs or other covers. Of these, the first and last deal with destruction or confining of adult flies; the remainder with control of the developmental stages.

Burning.[23]—Adult flies may be destroyed by burning them in their resting places with the aid of a gasoline torch.

Flooding.—The principle of *Psychoda* control by flooding seems to have been worked out by Headlee and Beckwith [7, 8] at Plainfield, N. J., although the fact that *Psychoda* larvae will suffocate if submersed for a sufficiently long time had been noted many years ago.[3] Headlee and Beckwith concluded from their studies that submergence for 24 hours was adequate to kill the fly and did not destroy the film. Putrefaction of the film, it was noted, set in after 36 hours. Headlee [8] states that practically all the organisms composing the society of which the fly is part can survive longer than *Psychoda* in the absence of atmospheric oxygen.

Flooding has been employed successfully at many plants. The time elapsing between floodings should naturally conform to the life cycle of the fly. As previously shown, the length of life of the fly between egg deposition and emergence will seldom be less than 8 days. Flooding is possible only when filter beds are water tight and walls and floors are capable of withstanding the hydrostatic pressures produced by filling the voids of the ballast with water. Means must be provided for controlling the filling and draining of the filters, and it is essential to continuous operation that flooding be restricted to sections of the available beds at one time. Filling and draining should be carried out as rapidly as possible in order to reduce "the period out of service" and to maintain the time of complete submergence as long as practicable without injury to the film. In this connection it must be remembered that the greatest density of fly infestation is in the top 3 to 12 inches.

Contact-bed practice may throw some light on desirable rates of filling and draining. In these beds rates of filling and draining in excess of 0.1 to 0.2 ft. per min. of vertical rise or fall are generally avoided. With an average dosing rate of 400,000 gal. per acre-foot per day, 100 per cent greater rates during continuous discharge, 40 per cent void space and ¼ of the filter to be flooded, it would be possible to fill the isolated section of a 6-ft. filter in about one hour. This rate of vertical rise approaches the limiting value for contact beds. The rate of draining can be regulated readily. A maximum rate consistent with leaving the film undisturbed, while flushing the underdrainage system, should be secured. A small amount of film-sloughing is unavoidable. However, it will aid in the removal of eggs that are not killed by submergence.

Since the breeding season of *Psychoda* normally coincides with the period of greatest filter efficiency, temporary overloading of filters to permit sectional flooding is probably of little account. We must remember, however, that low stream flows are also associated with warm weather, as are greatest biochemical activity and oxygen demand.

Plant operators report in general that there is no appreciable reduction in filter efficiency as a result of flooding. In this connection, it may be well to take a lesson from the accumulated experience of contact-bed operation, by allowing the bed to rest for several hours after flooding.

Drying.—If a filter is allowed to get thoroughly dry, eggs, larvae and pupae will perish. Also, the fly will not lay her eggs in a dry filter. It stands to reason, however, that to permit thorough drying of a sufficient depth of filter, the "period out of service" must be measured in days rather than hours as in the case of flooding. Film destruction is also greater. It follows that drying cannot be as satisfactory a con-

trol method as flooding. Drying may be helpful, however, when filters are so constructed that they cannot be flooded. At Canton, Ohio,[29] drying has been employed to control surface growths and ponding. A week of resting was found to be necessary to dry the upper 12 inches of filter even in warm weather. Flooding had to be resorted to in order to control fly breeding.

Surface Barriers and Tight Walls.—The use of a surface barrier of small ballast, the pieces being not more than one inch in diameter, was early suggested by Wilson and Johnson.[4, 5] With material of this kind, the under-surfaces as well as the upper-surfaces of the ballast will be wetted by sewage, leaving no dry crevices through which the flies can penetrate into the filter or escape to the air. The small ballast should, preferably, be well rounded and from 6 to 12 inches deep. English operators [21, 25–27] are generally of the opinion that flies are most numerous where a rough clinker medium is in use, where filter walls are open, and where sewage distribution by means of fixed sprays is poor. Travelling distributors are said to be better than fixed nozzles.

Construction of filters with tight walls and a surface barrier of well-rounded ballast less than an inch in diameter may prove to present a satisfactory solution of the filter-fly problem. Surface clogging might be overcome by colonization of the water springtail or by surface application of chlorine or other film-destroying substances. Chlorine might also be applied to the sewage.

Filter Covers.—In small installations, it is possible to control aërial nuisance by providing a fly-tight cover for the filter. During very warm weather the temperature in glass-overs is said to rise sufficiently high to destroy large numbers of adult flies. The use of contact insecticides for the destruction of adult flies and the burning of the flies is somewhat simplified in covered filters.

It appears from the foregoing that physical control of fly infestation of trickling filters is distinctly more satisfactory or promising than are biological or chemical methods. With the exception of drying, all of the physical methods seem to fulfill their purpose quite well or to give promise of being able to do so. For the destruction or confining of adult flies, burning and covering are of value. For larva control, flooding is an established procedure. The use of proper surface ballast and tight walls needs further study.

Acknowledgments

Much of the material brought together in this paper was collected in a study made by the author some years ago as Research Associate of Metcalf and Eddy, Consulting Engineers, Boston, Mass. Many sources of information have been consulted and this paper is presented as a

summary of experience with a view to aiding further researches as well as answering some of the questions of the plant operator.

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Discussion

F. W. Jones, *Cleveland:* I might tell the experience we have at our Southerly plant in Cleveland. We have six acres of trickling filters which are so designed that they can be flooded. It is absolutely necessary at that installation that we have no flies. It is also essential that we have no odors and since most of the people are at home on Sunday we take the whole six acres and flood them on Saturday night, let them out Sunday night and we are all ready to go Monday morning.

R. R. Cleland: How much chlorobenzene is used?

Professor Fair: I don't remember the figures. The reference is in the paper.

C. F. Grace, *Polk, Pa.:* At the Polk sewage treatment works there has always been a heavy growth on the filters. Mr. Young says it compares with some of the plants around Baltimore. It has been necessary for good operation to rest a row of two laterals of the filter, daily. This year I decided I would give the filters a good flushing out and I cut off two rows of nozzles for a period of four or five days and, as some one here spoke about the larvae in the stones migrating to moisture, I accidentally discovered that when you dried the filters to a sufficient depth, you could force the larvae right through the filters and the resettling basins were full of larvae. I tried it at different intervals and I don't have more than one third the flies that I had last year.

Dr. W. Rudolfs, *New Brunswick:* I think Professor Fair is to be congratulated upon his excellent summary of the work on *Psychoda.* I have felt for a long time that something like that is needed because too many haphazard things are said in literature, and among the operators and the people who have something to sell. I think the summary of the work is very valuable.

Professor Fair has discussed the propagation of the fly. Some years ago I set an assistant upon the job of watching the flies, when, where, and how they propagated. She found that in the majority of cases propagation took place quite soon after emergence in dry places. She also observed, however, that in some cases propagation would start while at rest and the flies would fly up in the air and complete propagation in the air itself.

We have found that the time of control is a very important thing. Ordinarily, the operator will start to control while the nuisance is greatest. Try to control before you have the nuisance. Prevention is better than cure. If you are having filter fly troubles, and you are reasonably sure to have them, remember that control starting early in the spring is far more important than control later on in the season. If you have a hundred to start with and you kill ninety you have a smaller number to breed from, whereas if you have a million and kill ninety per cent you still have a goodly number left to continue. So, to start control early in the spring is a very important matter.

Professor Fair said colonization of *Achorutes* is rather easy. We attempted to colonize it at two different places. The one at Plainfield where we had provision for flooding, we kept mostly for observation. We found colonization very difficult because when you fill the bed the *Achorutes* are on the surface and when the water rushes out a goodly

number apparently go out with the water. The result is that they congregate in corners but do not spread over the whole bed and their effectiveness is much less.

Something about the question of killing the larvae. If the procedure is followed whereby you fill the trickling filter, then let it stand for twenty-four hours and then drain the bed—I believe that takes about 48 hours for the whole story—we have found that if these things are kept submerged for twenty-four hours a goodly part of them are actually killed but that a number are not.

Some years ago we had a scheme of filling the bed as rapidly as we could and then opening the valves wide so that the effluent will rush out, the idea being to wash the larvae out of the film or out of the filter out into the stream rather than to keep them in the filter itself. The submergence was less and their control was better. The larvae would be swept out and deposited in the stream. By distributing in the stream over a wide area they are not a nuisance whereas they are a nuisance in a place closely confined.

The plan of drying was widely advertised some years ago. Professor Fair put his finger on the answer to that. Drying takes a long time and doesn't bring good results. One of the reasons is that the larvae migrate with the moisture so that if you dry out the top layers of the filter the larvae may move a little farther down where there is moisture and you just put them in another layer rather than kill them. There is very little reduction unless you dry the filter entirely, and that takes a long time.

Another question brought up was the killing of the insects in closed filters. We made some studies about the effect of the temperature on the adult fly. We found that at 112° F. we killed the fly. It means therefore that if you enclose the filter and run it up to 120° F. the adult will be killed.

Mr. Kinsel, *Philadelphia:* I would like to ask if you are familiar with any attempts to kill *psychoda* larvae in sludge drying on a sludge bed.

Dr. Rudolfs: Some years ago we tried doing that and we found that a sprinkling of caustic lime is about the best thing—it pretty well controls the larvae and you are not concerned with any bacteriological effects on the surface.

MODERNIZING TRAVERSE CITY'S SEWAGE DISPOSAL SYSTEM

By J. A. Volk

Supt.-Chemist, Sewage Treatment Plant, Traverse City, Michigan

Traverse City is located near the center of the resort country of Northern Michigan. It has a population of approximately 13,000 inhabitants.

Traverse City's first attempt to modernize its sewage disposal system was started in 1914, when a plan for the required adequate sewage facilities was proposed, and submitted to the voters. This first attempt met with failure.

Nothing further was accomplished until 1926, when the problem was again brought to the attention of city officials. At that time the city commission engaged a firm of consulting engineers to draw plans for a method of satisfactorily disposing of the city's wastes. An intensive study of the problem was made by the engineers, and the results of these studies were reported to the commission. The project involved the construction of a sewage treatment plant, to be located on a tract of land some distance from the more thickly populated section, near the southeastern city limits, together with the necessary intercepting sewers and appurtenances.

At the general election of April 4, 1927, a bond issue of $240,000 was submitted to the voters, but it was defeated.

In 1928, a proposition was submitted the voters for an amendment to the city charter, the amendment to be such as to conform with the provisions of Act 320, of the Public Acts of 1927, the original sewage-treatment utility act of this state. This proposed charter amendment also failed to carry.

In May, 1929, still another amendment to the city charter was voted on, this time to allow the granting of a franchise to a privately owned company to construct and operate a sewage disposal system on a utility basis. This proposition was very decisively beaten at the polls.

Again, at the April election in 1930 another proposition for bonding the city for the construction of a sewage disposal system was submitted to the voters and again the project was defeated, this time, however, by a very scant margin.

Following this last unfavorable vote, a survey of the bay and river waters was made by the State Stream Control Commission. Conditions were found to be such as to be a menace to public health and welfare.

Analytical data showed a *B. coli* index of one million and ten million,

in many instances, in the samples of water taken at various sampling stations along the river and at several of the bathing beaches. As a result a suit was brought against the city to end the pollution of these waters. In March, 1931, the Circuit Court handed down a decision which upheld the contentions of the state. The court decision left the city with no practical alternative to the construction of a sewage disposal system.

In the Fall of 1931, the city commission engaged the firm of Hoad, Decker, Shoecraft and Drury, consulting engineers of Ann Arbor, to review their 1926 report, modify it where the occasion demanded and to report on the cost of the complete revised project. This supplementary report recommended a change in the site for a sewage disposal plant from that originally selected, to one closer in, on land which the city owned. The new site selected for the treatment plant made it necessary to change the design somewhat, and the newly designed plant was found to be more expensive to build. However, the savings effected in the cost of sewers and lower construction costs than prevailed when the previous bond issues were submitted brought the final costs down so as not to exceed those originally estimated.

The second step taken by the city commission following the receipt of the plans, in this, the sixth attempt at trying to modernize the city's antiquated sewage system, was the inauguration of a very extensive educational program, in which the people of Traverse City were given in detail every bit of information concerning the plant and sewer locations costs, and kindred information in which the benefits to be derived from the construction of such a sewage disposal system were stressed. With the facts of the issue, in their entirety, before the people, a special election was called for October 23, 1931. The results were very gratifying, as the voters by a large majority cast their ballots approving the issuance of bonds to finance the construction of the new sewage disposal system. The city commission immediately authorized the preparation of working plans and specifications, and by the end of the following month, the contract for the first unit of the new project, the laying of the two pumping mains, was awarded. The treatment plant was completed in September, 1932, ready for operation. That part of the seeding and landscaping of the treatment plant and pumping station grounds that remained was finished in the spring following. The time actually required from the passing of the bond issue to the realization of this objective was but ten months. Twenty years of untiring effort were finally rightfully rewarded. The plant was officially dedicated one year after being put in operation, during the convening of the Michigan Municipal League in Traverse City, September, 1933.

The existing sewer system in Traverse City is for a large part a com-

bined sanitary and storm-water system. All sewers except those laid in recent years were planned and built with no particular consideration for future collection and treatment of the sewage they carried and their outlets were the most convenient point available along the river and bay.

The design of the new system provided for collection of all of the dry-weather sewage flow from the various parts of the city and for suitable storm-water overflows as necessary.

The city is divided into six sewer districts.

All of the main trunk sewers either relieve existing overloaded sewers or provide facilities for districts not previously served. In 1930 an agreement was entered into by the City and the State of Michigan, whereby the State constructed the so-called State Hospital sewer, later being reimbursed by the City in the form of credit against its share in the cost of the interceptor, pumping station and treatment works. The agreement also provided for a participation in the cost of operation of the plant on the basis of a percentage of sewage flow. This is determined by weir measurements at the point where the sewer leaves the institution grounds.

The readings are made hourly, over a twenty-four-hour period, four times a month, and the percentage determined from the total flow to the plant on corresponding days. The flow from the State Institution for 1933 average .309 million gallons daily, or 20.4 per cent of the total flow to the plant for the year.

By means of specially designed diversion chambers located at advantageous positions along the route of the main interceptor, the storm-water flow to the plant can be regulated.

The construction of a river wall 1140 ft. long along the south bank of the river not only provided a much needed improvement to the property along this side of the river, but also furnished a perfectly solid foundation upon which that section of the interceptor could be laid.

Main Pumping Station

The main pumping station is located just three blocks from the heart of the commercial district on East Front Street, which is the city's main thoroughfare and a state trunk line highway. The fact that it is so conspicuously situated made it necessary that it be designed so as to present something more than just the ordinary in architectural treatment and in such a manner that absolutely no odors would result from its presence.

The building (Fig. 1) measures 24 by 40 feet, the exterior is of a high quality, tan face brick construction with cut stone trim and tile roof, and adds considerably to the general appearance of the street upon which it fronts. The interior treatment with tile walls painted, concrete floors and ornamental railings and stairs, is very pleasing to the eye.

A gallery, a motor floor and pump floor comprises the interior floor arrangements. The motors are direct-connected by vertical shafts to the pumps. The transformer room, the automatic float switches, a lavatory and toilet are located on the water floor. The pump floor, which is at a level below the river and incoming intercepting sewers, carries four De-Laval centrifugal sewage pumps, which handle the sewage from the entire city. The smallest of the pumps, with a rated capacity of 900

FIG. 1.—Main pumping station.

g.p.m., is used mostly for handling the dry-weather night flow; the second pump, with a rated capacity of 1200 g.p.m., is used for the daytime dry weather flow; the two larger pumps are cut in at all times during this normal flow, but very seldom are they pressed into service. During storm-water periods the rotation of the pumps is just reversed and the two larger pumps, with a rated capacity of 1,500 g.p.m. each, carry the brunt of the load. The pumps are arranged so that by adjusting the floats, they cut in and out with the variation of the volume of the incoming sewage.

All sewage entering the pumping station is discharged into a well eight feet deep, 6 ft. wide and running the entire length of the station, access to which can be obtained by means of a small steel door in the floor above. Rubber gaskets line this door to prevent odors from arising from the well, so that no sewage is exposed to the air anywhere in the station. From this well the sewage is pumped through a 16-in. cast-iron pumping main to the treatment plant, a distance of approximately one-half mile.

The recording Venturi meter at the treatment plant indicates at all times how the pumps are working.[1] A clog or partial clog in a pump will

be indicated by a downward fluctuation of the recording pen arm on the meter, and when this occurs an operator immediately journeys to the pumping station and remedies the fault. Much of the difficulty encountered is due to rags from the State Hospital sewer. An inspection plate, which can be removed by unscrewing two bolts, gives the operator convenient and rapid access to the interior of the pump. The only detail required to entirely eliminate such clogging of pumps as occurs, would be the installation of a coarse bar screen ahead of the pumps. The station temperature is kept above the freezing point by means of three — 3,000 watt thermostatically controlled electric heaters, the operating costs of which are included in the pumping costs, so that during the months these heaters are in use the pumping costs apparently increase somewhat. The power is supplied by the city's Light and Power Department and is paid for at the same rate, assessed to all users alike. The power rates are 4c per K.W. for the first 400 K.W., 3c per K.W. for the next 600 K.W.; 2c per K.W. for the next 1,000 K.W., and 1½c per K.W. for all in excess of 2,000 K.W. The cost of power for pumping in 1933 averaged $3.47 per million gallons. A daily record of the actual pumping time of each pump is maintained and compared with the rated capacity of each pump. This procedure allows a close check to be maintained on both the efficiency of the pumps and the accuracy of the recording Venturi meter. The average pumping head is twenty-two feet, including all friction losses.

Sewage Treatment Plant and Operation

The treatment plant is a separate-sedimentation and sludge-digestion type, with year-round chlorination of settled effluent. Its proximity to the railway station, a public restaurant, the newly constructed municipal skating rink and many residences made it necessary that it be attractive and, more important, absolutely free from odors.

Three units, the main building, the digestion tanks and the drying beds comprise the layout of the plant grounds. The seven-acre tract upon which the plant is situated is beautifully landscaped and a paved roadway gives access to all buildings on the premises.

The forepart of the office building houses the offices of the city engineer, the plant superintendent and the laboratory. The laboratory is completely equipped in every detail for the technical control of the plant. Routine analyses are made every fourth day, while *B. coli* and 37° C. counts of the plant effluent, bathing beaches and samples of river water taken from established sampling stations below the effluent outfall, are made once a week. A daily record of operations is maintained on all functions of the plant and pumping stations. The effluent outfall enters the river at a point where it joins the lake. The normal flow of

the river is 350 C.F.S. and complete diffusion of the plant effluent with the river water is assured by the time it has reached a point 300 feet below the outfall.

Adjoining the offices and laboratory in the fore part of the building is the chlorinating room, directly over the chlorine storage room. It contains a Wallace and Tiernan vacuum-type solution-feed chlorinator, with a maximum capacity of 300 pounds per 24 hours. Originally a smaller type was used but was found to be inadequate for summer use, when the settled effluent requires a much heavier chlorination, and consequently the larger orifice was installed. A Fairbanks springless scale of 10,000 lb. capacity is provided in the chlorinating room, upon which are kept two one-ton containers of liquid chlorine, both connected, but only one in use at a time. The chlorine is side tracked and trucked from the multi-unit car to the plant, a distance of about 500 feet, where it is lowered into the chlorine storage room, which is equipped with a draft ventilator. An overhead two-ton hoist, which runs through the chlorine room, through the entire length of the settling tank room and into the garage, is used to unload, raise and lower the containers. A total of 62,839 pounds of chlorine were used during 1933, an average of 172.5 pounds per day. A residual of from 0.5 to 0.8 part per million is maintained throughout the summer months. During the winter months a residual of 0.2 part per million and not to exceed 0.5 part per million is maintained.

The wash room, lavatory, locker room and storage closets, constitute the remainder of the space occupied by the office unit of the building.

From the chlorine room large hollow steel doors open into the settling tank room which also houses the grit chambers, chlorine dosing tank, bar screen and the effluent outfall chamber. The sewage first enters the grit chambers. There are two of these, which are alternated each week, except when the flow exceeds a rate of 4 m.g.d., in which case both are used for the duration of this heavy flow. The velocity is 50 feet per minute at 2 m.g.d. This velocity permits all sand, gravel and other grit to settle but the organic matter will be carried along, to be removed later in the settling tanks. The grit removal for the first full year of operation averaged 5.6 cubic feet per million gallons. The source of the bulk of this grit is, of course, the combined sewers. The organic content of the grit removed averaged 21.24 per cent. A period of 48 hours for draining is allowed from the time the grit chamber is taken out of service to the time it is cleaned.

Leaving the grit chamber the sewage passes through the Dorrco bar screen, where rags, debris and coarser solids are removed by an electrically operated mechanism. They are deposited on a concrete hopper, which is covered completely with a galvanized steel hood. The hopper

has a capacity of 3 cu. ft., therefore removing the screenings once a day under normal conditions is enough to keep the hopper cleaned. From the hopper the screenings are removed to the fire-clay drying bin directly over the incinerator, which uses gas generated in the digestion tanks as a fuel. Screenings are burned daily. Average production amounts to 1.7 cubic feet per million gallons.

After passing through the bar screen the sewage is distributed to the four settling tanks. These tanks have a total effective volume in settling compartments of 250,000 gallons and will provide a nominal detention period of three hours with a flow of 2 m.g.d. The average removal of settleable solids is approximately 96 per cent. The settling tank effluent passes from these tanks into the chlorine contact chamber, where the chlorine is applied. The contact period is 15 minutes with a flow of 2 m.g.d. At the west end of the contact chamber the chlorinated effluent enters the outfall sewer, which conveys it to the river.

Provision is made for skimming grease and floating materials from the surface of the settling tanks, through the use of skimming troughs near the outlet end of each tank. The procedure followed in operating the skimming troughs, and one that was found to be to the operator's advantage, was to close the 16-inch effluent outfall valve partially, backing up the sewage in the chlorination tank, outlet weirs and settling tanks to a point where the water level comes just to the lip of the trough, thus allowing all floating matter to flow into the trough, which carries it to one central collection tank. This tank is designed so that the water bearing the skimmings can be drained off, leaving only the solids, which are disposed of either by burning in the incinerator or are hauled away with the grit, which is taken to the municipal dumping grounds located outside of the city limits.

The mechanism which collects raw sludge in the settling tanks and deposits it in a hopper preparatory to being pumped to the digestion tanks, also serves to keep the surface of the settling tanks clear of all floating matter by carrying it to the trough end of the tank, thus performing the two functions in one operation. This mechanism is operated approximately one hour per day.

Adjoining the settling tank room is the garage, the ground floor of which provides a place for storage of plant trucks and automobiles. It also houses a work bench, lavatory, the control board for the bar screen, ventilator fan and motor and the drying bin for screenings.

One of the most important elements of the entire plant is the ventilating system, just mentioned, which has been provided for ventilating the settling tank room and the sludge drying beds. By means of this ventilating system air can be withdrawn from the room in which the settling tanks, bar screen and grit chambers are located and the sewage

is exposed. It is discharged into a 75-foot chimney (Figure 2) where it mingles with the hot gases of combustion from the boilers and incinerator.

By means of this same ventilating system the sludge drying beds can be ventilated when fresh sludge is being withdrawn. Underground conduits leading from the drying beds to the ventilating fans provide the outlet for these gases and other foul air. With this complete system of

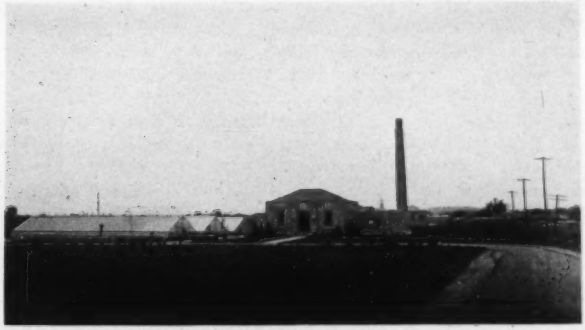

FIG. 2.—Sewage treatment plant, showing 75-foot chimney and glass-covered sludge drying beds.

ventilation, the odors in the settling tank room itself, which constitutes the greatest source of odor in the building, are minimized so that at no time have they ever been the cause of unfavorable comment.

The basement floor of the garage contains three sludge pumps, two Bryant gas burning furnaces, transformer room and the incinerator. The sludge pumps are Rex single-plunger type having a minimum pumping capacity of 17 g.p.m. and a maximum pumping capacity of 60 g.p.m., with a total of six different pumping rates obtainable by the use of a two-speed driving motor and three adjustments on the pump plunger.

The Bryant furnaces, each having a maximum burning capacity of 300 cubic feet of gas per hour, are used for heating the buildings and digestion tanks. The incinerator of Morse-Boulger construction, has been found to be a very valuable asset to the plant and to the city, burning not only screenings and skimmings from the plant, but also obnoxious weeds, mainly ragweed, collected during summer campaigns in what has been a successful effort to rid the community of these elements.

From the garage basement a large passageway leads to the west and gives the operators easy access to the digestion tank sampling cocks, ther-

mometers and the sludge line valves. Overhead are the steam lines, cold water return and supernatant return line from the digestion tanks, running back directly to the settling tanks.

The long passageway or pipe gallery leading to the basement under the offices runs between and on the same level with the settling tank floors, and makes the sludge line valves from the settling tank hoppers and the grit chamber drain valves accessible.

Another interesting feature of our plant is the floor drain system. All wastes and flushing water have an outlet in the floor drain system. Together with the wastes from the lavatory and toilet, they empty into a sump located at the lower end of the pipe gallery, where an automatic pump delivers all accumulations into the sewage distribution line, and thence into the settling tanks.

The two digestion tanks, each measuring 45 feet in diameter and 17 feet in depth, afford sufficient capacity for the plant's requirements. The effective sludge digestion capacity is 45,000 cubic feet. The tanks are completely covered with the typical mound of insulating earth cover, so familiar at all sewage treatment plants of this type. A well-kept lawn and a small eight-sided superstructure over each tank housing the digestion tank mechanism and gas collecting dome are the only visible structures of these units, exclusive, of course, of the manholes with which all digestion tanks are equipped. The small buildings are very artistically designed and conform with the general architectural design of the plant itself.

The sludge stirring and collecting mechanisms were furnished by the Dorr Company. The tanks are also equipped with heating coils. All gas produced in the two digestion tanks is piped into the plant and separately metered. The gas production for 1933 averaged about 0.75 cu. ft. per capita per day. So far this gas production has not been quite adequate for the demands of the heating system during winter months.

A little difficulty with foaming was encountered when the first digestor was put in operation. This tank was seeded with about twenty barrels of digested sludge from the septic tanks at Cadillac, plus an additional amount of raw sludge. With the aid of several tons of lime and the lowering of the tanks contents this condition was overcome in less than a week's time. The gas supply, however, was not sufficient to supply both boilers and for about three months during this first winter of operation an oil burner was installed in one of the furnaces to supply the necessary heat.

The second tank was seeded with digested sludge from the first tank and no trouble whatsoever was experienced in putting this tank into operation much to the surprise of the superintendent and operators.

Raw sludge is removed from the settling tanks daily. This method

of pumping resulted from a long series of experiments in an attempt to determine the most satisfactory method of handling raw sludge. An average of 3,000 gallons of raw sludge having an average moisture content of 92 per cent, and an average volatile content of 74 per cent, is pumped to the digestors daily, alternating pumpings when both tanks are in service.

A total of 59,250 gallons of digested sludge was drawn to the drying beds during the first year of operation. This sludge had an average moisture content of 90.5 per cent and 59.4 per cent volatile solids.

Digested sludge is pumped from the digestion tanks to the glass-covered drying beds, three in number and each having a total area of 4,000 square feet. Each bed is divided into two separate compartments by an 18-inch concrete partition, each compartment having an outlet for digested sludge, which as a general practice is distributed to a depth of about 10 inches. A concrete driveway runs the entire length of each compartment, measuring 100 feet in length, thus allowing the trucks to back in continuously as the sludge is being removed. Sludge having a moisture content of 92 per cent has been dried to a 3 per cent moisture content in 10 days. This, however, is not the average. Temperatures ranging to a maximum of 216 degrees Fahrenheit have been recorded inside the drying beds. This highest temperature was recorded when the temperature outside the drying beds in the sun registered 96° Fahrenheit. The three primary reasons for having glass-covered drying beds are: first, to minimize and uniform the drying period made necessary by the somewhat limited drying area; second, to minimize the odors, and third, appearance.

The dried sludge was used quite successfully during the past summer on an experimental truck garden conducted by the staff. Facilities for pulverizing and dispensing dried sludge on a commercial basis have not been arranged as yet, but the demand is such that it will warrant doing so, thus supplying an additional revenue for the plant. The fertilizer has been found to be ideally adapted for the sandy soil in the surrounding territory. To date, all dried sludge has been given to those requesting it, and reports of the benefits derived in every instance have been favorable.

Operating Records

The following table summarizes the results of operation of the plant during the year 1933.

A comparison of conditions in the Boardman River and the Bay from a bacteriological standpoint before and after the installation of the sewage treatment plant may be of interest. The following chart and table shows sampling points and results of bacteriological analyses of samples collected at these points. It is regrettable that a greater num-

Sewage Treatment Plant

Traverse City Michigan

Summary of Monthly Operations

1933

Month	Air Temp., F.°	Sewage Temperature, F.°	Total Gallons Treated	Average Daily Flow, Gallons	Grit			Screenings		Settling Solids c.c. per liter		Total Solids P.P.M.				Suspended Solids P.P.M.				5-Day B.O.D. P.P.M.	
												Total		Volatile		Total		Volatile			
					Cu. Yds. Removed	Per Cent Moisture	Per Cent Organic	Cubic Ft. Removed	Daily Avg. Cubic Ft. Removed	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Raw	Sett.
January	23.6	48.3	45,603,000	1,471,000	11	35.6	27.9	140	4.5	3.820	3.50	583	451	401	292	227	98	171	77	163	93
February	20.7	44	50,849,000	1,812,000	9.25	24.2	14.4	91	3.2	3.857	2.91	524	409	378	284	187	79	149	66	160	80
March	28	46	50,140,000	1,671,000	6	29.6	15.9	84	2.7	3.750	2.12	480	377	330	254	165	71	119	53	175	102
April	39.3	47.8	47,855,000	1,595,000	6.5	30.2	19.8	63	2.1	4.070	2.35	476	401	310	249	173	71	139	56	175	110
May	56	52.6	50,339,000	1,623,000	10.25	29.7	15.2	80	2.6	3.750	2.37	480	383	311	245	151	63	116	43	149	95
June	69	60.2	40,650,000	1,355,000	8	36.4	21.2	71	2.37	3.812	1.88	499	413	323	249	181	73	127	50	175	112
July	71.7	65.3	48,335,000	1,559,000	9.75	28.2	15.5	62	2.17	4.786	2.36	609	485	403	322	175	70	144	55	187	137
August	66.2	67.2	42,512,000	1,371,000	12.75	35.2	32.7	59	1.9	4.000	1.75	537	410	357	283	177	70	135	54	188	120
September	57.6	64.9	40,305,000	1,343,000	9.25	49.5	28.2	61	2.06	3.935	1.56	537	405	354	292	181	71	140	60	202	128
October	39	59.3	48,198,000	1,554,000	12	40.6	13.8	76	2.46	4.375	1.82	537	406	365	269	169	64	139	50	204	144
November	21.5	53.8	43,432,000	1,447,000	5.75	46.6	22.1	69	2.3	3.285	1.22	506	384	360	254	150	53	124	43	165	118
December	17	51.5	43,338,000	1,398,000	6.75	47.2	26.2	74	2.37	4.500	2.00	571	402	286	248	185	69	161	53	163	110
Total			551,556,000		107.25			930													
Maximum	71.7	67.2	50,849,000	1,812,000	12.75	49.5	32.7	140	4.5	4.786	3.50	609	485	403	322	227	98	171	77	204	144
Minimum	17	44	40,650,000	1,343,000	5.75	24.2	15.5	62	1.9	3.285	1.22	476	377	286	245	150	63	116	43	149	80
Average	42.4	55.1	45,963,000	1,516,000	8.94	36.1	21.24	77.5	2.56	3.995	2.15	528	410	349	270	177	71	138	55	175	112

Sewage Treatment Plant

Traverse City Michigan

Summary of Monthly Operations

1933

Month	Chlorination		Daily Avg. Lbs. Used	Raw Sludge			Digested Sludge			Digestion Tanks				Total Cubic Ft. Gas Produced
										No. 1		No. 2		
	P.P.M. Used	Lbs. Cl. Used		Gallons Pumped	Per Cent Moisture	Per Cent Volatile	Gallons Pumped	Per Cent Moisture	Per Cent Volatile	Temp.	Cubic Ft. Gas	Temp.	Cubic Ft. Gas	
January	11.5	4,821	158	170,000	93.1	74.2		88.3	74.1	62	94,400			94,400
February	10.1	4,308	154	133,800	91.6	73.8		86.5	70.3	61.1	114,120			114,120
March	12.6	5,137	168.3	85,900	90.0	72.7		90.9	65.0	63	140,030	42	1,410	141,440
April	13.4	5,309	177	75,600	91.0	71.8		91.6	58.4	65.8	146,475	43	12,625	159,100
May	13.6	5,664	183	72,100	90.6	72.8	5,250	90.8	57.1	66	156,875	46.2	21,550	178,425
June	15.5	5,336	177.8	97,950	90.7	72.5		90.8	56.4	77.7	213,810	55	50,370	264,180
July	17.4	6,973	225	147,900	91.2	75.5		91.0	56.9	86.5	308,800	74.9	170,000	478,800
August	17.6	6,250	202	152,800	91.8	75.1		91.4	55.8	83.7	172,500	81	131,515	304,015
September	16.3	5,228	174.3	146,700	91.7	74.2	9,000	90.1	53.6	85.3	161,600	84.8	138,650	300,250
October	12.5	4,955	160	116,100	92.1	72.9	9,000	90.4	55.4	69.4	71,040	81	133,100	204,140
November	12.7	4,620	154	107,400	92.2	77.2		91.6	52.0	48.9	13,050	77	213,825	226,875
December	11.5	4,238	136.7	86,700	92.7	79.1	36,000	92.1	57.8	40.8	2,350	74.9	252,150	254,500
Total		62,839		1,392,950			59,250				1,595,050		1,125,195	2,720,245
Maximum	17.6	6,973	225	170,000	92.7	79.1	36,000	92.1	74.1	86.5	308,800	84.8	252,150	478,800
Minimum	10.1	4,238	136.7	72,100	90.0	71.8	5,250	86.5	52.0	40.8	2,350	42	1,410	94,400
Average	13.73	5,237	172.5	116,080	91.56	74.3		90.5	59.4	67.5	132,921	66	112,519	226,687

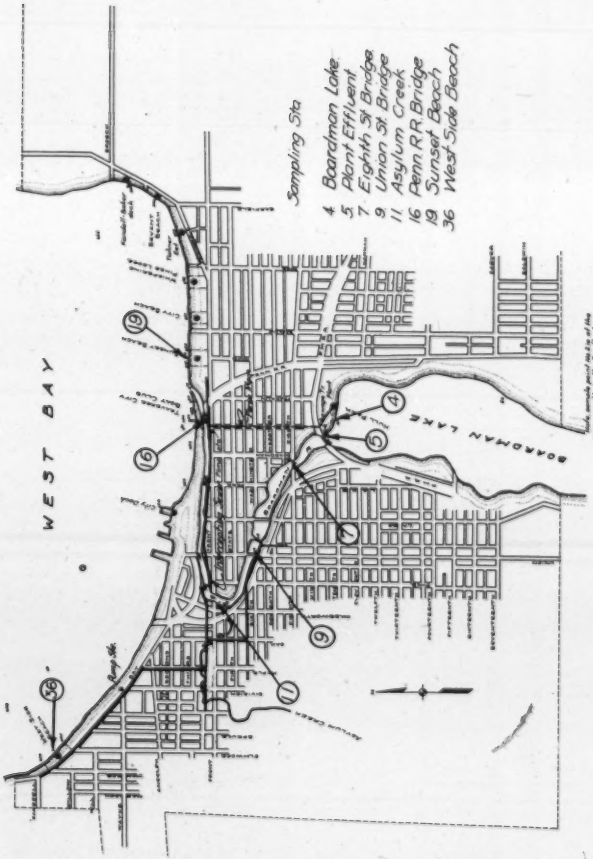

FIG. 3.—Sampling point locations.

TRAVERSE CITY SEWAGE TREATMENT WORKS

Tabulation of Bacteriological Data Showing Logarithmic Averages of 37° Count and B. coli Index at Various Stations Before and After Sewage Treatment Works Were in Operation

Station	37° Count		*B. coli* Index		Number of Samples	
	Before	After	Before	After	Before	After
4—Boardman Lake	195	100	620	3	3	51
5—Plant Effluent	140	72	1,000,000	12	1	51
7—Eighth St. Bridge	950	51	1,950	92	18	54
9—Union St. Bridge	3,180	92	16,000	135	5	54
11—Asylum Creek	5,850	1,300	100,000	3,900	5	51
16—Penn. R. R. Bridge	27,000	610	1,290,000	780	18	53
19—Sunset Beach	4,930	568	20,000	410	20	31
36—West Side Beach	437	178	240	85	18	31

ber of samples had not been collected before the plant went into operation, since the few samples collected from stations show a wide variation. In order to minimize the effect of the wide divergence of some of the samples the table shows a logarithmic average of the values for each station, rather than a mean value. The high values obtained at Station 11 are probably due to pollution entering the Asylum Creek from private residences. It is likely that there are still some private connections to Boardman River (there are perhaps six or eight connections between 8th Street and Union Street bridge) but all but these few have been eliminated.

The cost of operation for 1933 is distributed as follows:

Power, Light and Water:		
Front Street Pumping Station	$1,923.10	
Bay Street Pumping Station	261.19	
Treatment Plant	759.77	
		$ 2,944.06
Superintendence and Labor:		
Superintendent, Operators and Labor		$ 6,732.36
Chlorine and Supplies		2,776.57
Maintenance and Repairs:		
Front Street Pumping Station	$ 42.72	
Bay Street Pumping Station	11.50	
Treatment Plant	274.75	
		$ 328.97
Total		$12,781.96

Income for Maintenance and Operation

The cost of maintenance and operation is financed by the revenue obtained from sewer rental charges, participated in by those residences and business places connected, the rates being as follows:

First 3,000 cubic feet	at 80¢ per M
Next 10,000 cubic feet	at 40¢ per M
Next 10,000 cubic feet	at 20¢ per M
All over 23,000 cubic feet	at 10¢ per M

Minimum charge per quarter is $2.00, with 5 per cent discount allowed if paid on before the 15th day of the month after the expiration of each quarter.

This schedule is based upon the metered water consumption and in very few instances does the quarterly residence charge exceed the minimum. Provision is made for the two summer quarters, when so much water is used on lawns, by using the average of the two winter quarters thus making the charges more or less uniform for all four quarters.

The bond payment and interest for this year and for some years to come will be provided for in the annual budget to be raised by general taxation.

Originally it was planned to include all costs, both maintenance and operation and the interest and bond retirement, in the service charge. The annual revenue derived from service charges is approximately $18,000. This provides ample funds for the maintenance and operation of the plant, but insufficient to include the payment of interest and bonds, so until such time as the revenue is sufficient to defray the interest and bond payments, this item will be included in the annual budget.

Operating Personnel

The personnel consists of C. E. Sawyer, Superintendent and City Engineer; J. A. Volk, Plant Superintendent and Chemist; an operator mechanic, and a night operator. All sewer cleaning, repairing and maintenance work is done by the personnel of the general street department, which department includes the sewage disposal system.

The plant was designed for a population of 25,000 people and at the present time serves a connected population of approximately 12,000, in addition to some of the storm water. Since going into operation the plant has handled the sewage from the entire city and the state institution continuously, with the exception of several hours shortly after the plant was started, when minor adjustments necessitated a short shutdown.

The elimination of sewage pollution in the river and bay is manifest to the layman by the fine appearance of the water in the river and the extent to which the water in the bay in general and the public bathing beaches in particular has been purified. These beaches were opened

again to the public last summer after having been closed by order of the State Health Department for the past two years.

Another of the many gratifying results brought about as a result of the plant being put into operation is the decrease of approximately 60 per cent in the amount of chlorine used in chlorinating the city's water supply, which is pumped directly from the bay. It is hoped this use will be still further decreased as the effect of years and years of accumulation of pollution disappears.

Cost of the Entire Project

The total cost of the entire project is given below in the following table:

Intercepting Sewers		
Hospital Sewer (built in 1930)	$15,209	
Main Intercepting Sewers	38,059	
		53,268
River Wall		31,013
Bay St., Oak St., and Cass St. Trunk Line Sewers		41,344
Pumping Station Bay St.	4,832	
Pumping Main	2,162	
		6,994
Main Pumping Station	18,576	
Pumping Main	11,818	
		30,394
Treatment Plant and Outfall		127,401
Total Cost		$290,414

Of this total, the State of Michigan, because of the state institution, has shared to the extent of $41,325. The city's bond issue called for an expenditure of $245,000. Only $235,000 in bonds were issued, however, as the entire project was built below the engineers' estimate. Special assessments were levied against property abutting on the three district sewers, that had no previous sewer assessment; this assessment totaled $14,186. The total of these three sources of financing is $290,511, an excess over the actual cost of the work.

The project has been carried through under the administration of Charles C. Wells, Mayor; G. Arnell Engstrom, William Hogan, Ralph H. Smith, William Abbott, Commissioners; and Charles E. Sawyer, City Engineer; Hoad, Decker, Shoecraft & Drury, Consulting Engineers, of Ann Arbor, designed and supervised the construction of the entire project.

Stream Pollution

STUDIES OF POLLUTION OF NEW YORK HARBOR AND THE HUDSON RIVER *

By Earle B. Phelps

Professor of Sanitary Science, Columbia University, New York City

The pollution of the waters of New York Harbor and its tributary streams has been the subject of continuous and, at times, intensive study since the appointment of the New York Bay Commission in 1903, the work of which was absorbed into that of the Metropolitan Sewerage Commission, 1906–1914. Routine studies of dissolved oxygen and other observations have since been made by the Board of Estimate and Apportionment and later, as at present, by the Department of Sanitation. The Metropolitan Commission made the most extensive studies in the sense both of time and of area covered and their data remain to the present time our chief store of analytical material. The continuous record for the summer months, from 1914 to the present, although rather meager in any one year, provides data for a study of the trend which are of great value.

The collection of data of this sort is a matter of the first importance. It records the facts at any given time and place and thus provides a record of past and present day conditions. A second and equally essential requirement to any real understanding of the situation is the analysis of the data in terms of some general formula which will show the relation between the physical constants, population, stream flow, tidal circulation, reaeration, etc., and the resultant condition of the water. Such a formula should be rational to the extent that the physical constants and their effects are known; and the relative test of its applicability is the degree of accuracy with which it reflects the actual analytical picture from year to year and from place to place in the harbor. If the formula fits the record with a reasonable accuracy it may be used with some assurance to forecast the result of an increasing or shifting population or of specific remedial measures.

The ability to forecast is, in fact, the only real justification for undertaking this type of study. The past is fully recorded and is of practical present interest only as one projects it, consciously or unconsciously,

* Presented at the Annual Meeting of the New York State Sewage Works Association, New York City, January 16, 1934.

into the future. It is almost essential also, in the face of large capital expenditures for treatment works, that the effect of any specific project upon the whole harbor be predictable.

An attempt to formulate the New York Harbor situation in some such manner was made by General William Black and the writer in 1910. This was before the conception of the B.O.D. methods. Our report in fact contains the first suggestion, of which I am aware, of using this quantitative concept. In fact the idea of relating sewage analysis to oxygen requirements in the harbor was so novel that the Metropolitan Sewerage Commission was led to state in its 1914 report, "It is impossible to say with any useful degree of accuracy how many pounds of oxygen one million gallons of sewage will require in order that the putrefiable ingredients may be rendered inert. The two ways of approaching this, that is by analysis and incubation tests, are unfortunately too artificial to show what may be expected in Nature." This was a very fair statement of the situation at that date.

As now viewed our ideas were crude and partly erroneous. We were certainly luckier than we deserved, for our studies of the sewage of a part of Brooklyn led us to adopt a figure of 0.2 lb. for the value of the constant which, in our present-day terminology, would be called the ultimate daily B.O.D. per capita. The accepted value twenty-four years later is 0.22 lb.

In view of the exaggerated idea which prevailed at that time with respect to the feature of reaeration, we gave that matter considerable attention. The late Edlow Harrison had advised the Passaic Valley Sewerage Commission that, by reaeration alone, New York Harbor waters could oxidize the sewage of 60 million people. This estimate was based upon an obviously incorrect application of the experimental data of Professor Adeney but when the latter was called to advise the Metropolitan Commission later he expressed the view that the rate of absorption of oxygen in New York Harbor would be completely counterbalanced by reaeration "if the sewage were settled before discharge" and that this condition would be maintained "for many years to come." Professor Adeney avoided coming to any detailed quantitative estimates of his own, although criticizing ours as being far too low. It is interesting therefore to note that the only figure he ventured upon and which he qualified as a probable maximum value is almost identically the figure which we used for the mean reaeration index for the whole harbor.

We divided the system into seven parts and determined the average pollution of each part as affected by its own immediate contributing population and by the tidal interchange through the system. All computations were based upon mean summer conditions of tide and Hudson River run-off. The results appeared as a series of mean values for each

of the seven sections and for the ends of both the ebb and flood tides. A year later and thereafter the extensive data of the Metropolitan Commission became available. Our estimates were found to be in remarkably close agreement with average values for the various sections computed from these data but the comparison required some selection and averaging to bring about comparable conditions because our values related to areas while the analytical data were largely at cross sections on the ebb and flow tides. As a basis of comparison let us consider one of the most important stations, namely, the Upper Bay. The mean of all summer values for 1909, 11, and 12, as reported by the Metropolitan Commission, and our computed values for 1910 are shown in Figure 1. The chart also shows the end of the 22-year trend line, to which reference will be made later.

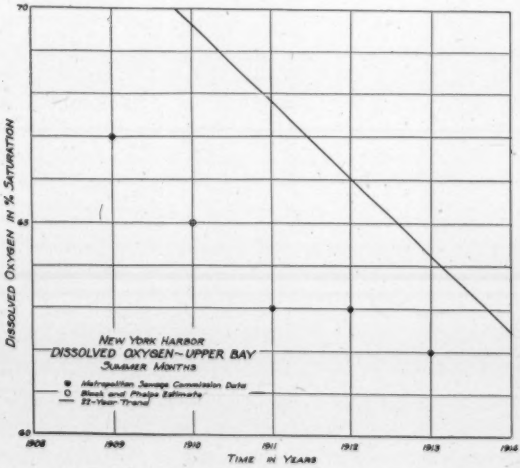

FIG. 1.—Dissolved oxygen in the Upper Bay, New York Harbor, as computed for the summer of 1910 and as determined for the summers of 1909, 1911, 1912 and 1913.

Our formulation being based upon mean summer conditions would naturally give, through successive years, a series of computed values varying only with population. The nature of the formula also suggested that the variation should be nearly linear with population. The record of the subsequent years actually showed quite a different picture. Instead of a smooth trend-line we have a saw-tooth contour with

rather extreme annual variations, as will be seen in Figure 2. This of course was to be expected as a result of other variables not considered in the formula but it would seem that a correct formula would at least show the correct trend through a period of years. The position of this trend line is indicated on Figure 2, by the "Population Trend." It appears from this that the oxygen depletion in the Harbor is increasing at a faster rate than the population.

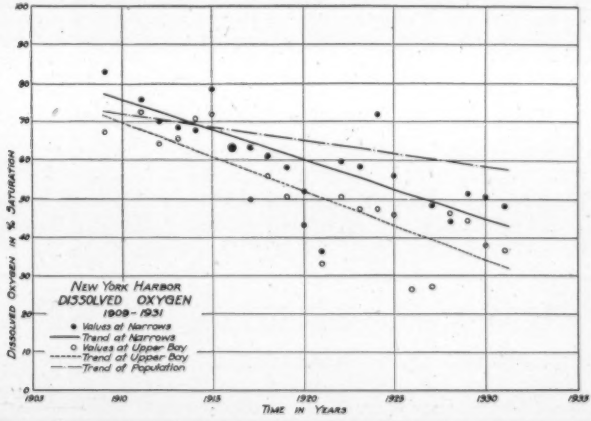

FIG. 2.—Dissolved oxygen at the Narrows and in the Upper Bay, New York Harbor, summer values 1909–1931 and computed trend lines. Also trend line of the population for the same period.

The writer's next active contact with this matter was in 1919 when litigation before the United States Supreme Court made it necessary to make a rather extensive analytical survey. At that time a very fair sampling of the Upper Bay gave an average of 50 per cent of saturation while the Black and Phelps formula indicated 48 per cent. At that time also the importance of the annual variations from the trend became apparent because of questions raised and inferences drawn by opposing counsel. Rather convincing testimony was in fact given by some of their experts that the trend-line was no longer downward. Mr. W. T. Carpenter undertook some correlation studies to see whether meteorological conditions were related to these variations, but with only partial success.

In 1931 Mr. Clarence J. Velz, under the writer's direction, undertook a review of the subject with special reference to the annual varia-

tions. They appeared to be primarily associated with the Hudson River run-off and this review was concerned chiefly with that aspect of the problem. It was found desirable, however, in view of the many advances which had been made in our knowledge of sewage chemistry since 1910, to analyze the data from an entirely new viewpoint. This viewpoint was a differential one dealing with gradients throughout the system instead of the integral seven-section system formerly employed. The end results of this study, as they apply to the water at the Narrows, are shown in Figure 3. Since the summer runoff of the Hudson

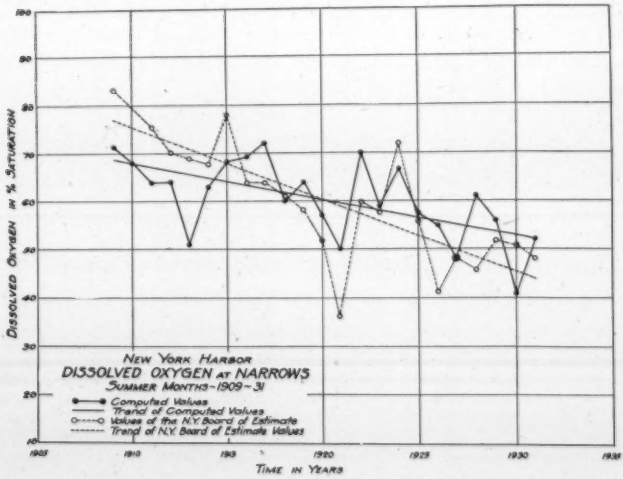

FIG. 3.—Dissolved oxygen at the Narrows, New York Harbor, summer values 1909–1931, with the trend line compared with computed values for the same period and their trend line.

River was included in the analysis the result gave us a sawtooth profile which in its major aspects corresponds with the actual data. This correspondence is of quite real significance because only the data of the Metropolitan Sewerage Commission were employed in defining the formula so that the fit, in subsequent years, is not merely a matter of determining appropriate constants. In spite of certain reasonable objections to some of our basic assumptions, we feel that this method of procedure gives us a fair approximation to the actual situation. If this be the case the differences now observed between the experimental data

and the formula must be due to actual experimental inaccuracies or to some further variation of basic factors not yet recognized. A plot of these actual differences between the computed values and the observed data, as seen in Figure 4, very strongly suggests a cyclic or periodic

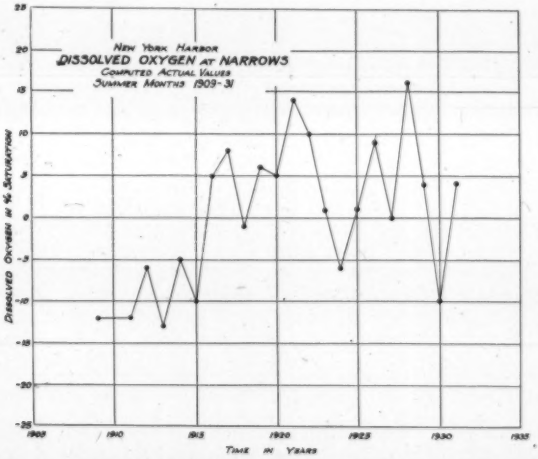

FIG. 4.—The differences between computed and actual values of dissolved oxygen in the Narrows, New York Harbor, showing the tendency toward a cyclic variation about the mean trend-line value.

condition which seems to be just now returning to the condition of 1910, giving approximately a 23-year period. A suggestion is the probability of a tidal period and a preliminary trial has given promise of an eventual causative factor based upon mean monthly tidal amplitudes.

A study of this final chart of differences also indicates that the downward trend of 1910 to 1930 was in fact primarily determined by the trend during the first 10 years, which was strongly downward, and that during the past 10 years it has been decidedly upward.

By this series of successive approximations we appear to be approaching an analytical formula which expresses the relation between the actual harbor condition, as measured by the dissolved oxygen, and the many variable controlling factors.

Discussion

By George A. Soper

So far as relates to New York Harbor, the oxygen test is now of more academic than practical significance.

Time has changed our point of view. When the test was first introduced, in 1909, we looked upon it as of the greatest value. It was to take the place of the complicated nitrogen determinations which up to that time had been customary in water pollution investigations. Dissolved oxygen, with admirable simplicity, seemed to strike directly at the heart of the matter. The disposal of sewage in water, as on land, meant the liquefaction of the solids and the oxidation of the liquids and, consequently, depended upon an adequate supply of dissolved oxygen in the water. So long as the water contained enough oxygen there was no danger that the organic matters introduced with the sewage would putrefy and give off offensive odors. It was because streams and arms of the sea were overloaded with sewage that the oxygen became exhausted and great stenches, such as that which had once occurred from the river Thames at London, arose. Knowing the amount of oxygen which would be present if there was no sewage whatever in the water, the amount which was found at any time or place indicated the burden of pollution which was being carried.

What, then, was a safe margin of oxygen to have always present? Opinions differed. Many experts were consulted, men of the greatest authority in this country and Europe were called into consultation. Some said there should always be at least seventy per cent of the saturation value of oxygen present. Most said from fifty to sixty per cent, and one said twenty-five per cent would be sufficient.

The Metropolitan Sewerage Commission, under which the investigation of New York's sewage problem had been placed by the City and State of New York, had prepared a standard of cleanness for the harbor in which a list of five minimum requirements was presented. There was to be no solid matter easily recognizable from boats and the shore as of sewage origin, no marked discoloration or turbidity due to sewage, no effervescence of foul gases, no noticeable odors, and no deposits due to sewage except, perhaps, in the immediate vicinity of sewer outfalls; the dissolved oxygen should not fall below fifty-eight per cent of the saturation value; and the quality of the water at points where bathing and shellfish culture were permitted should conform substantially, as to bacterial purity, to a drinking water standard. The Commission eventually eliminated all reference to dissolved oxygen, being convinced that if the other specifications of its standard were complied with, there would always be sufficient oxygen present. It was convinced that there

was no single test which, when applied to the water of any part of the harbor, would show the concentration of sewage pollution which there existed.

Time has justified the abandonment of the oxygen requirement. It would have been well if the subject had never been brought up, for it has served for twenty-five years as a source of continual argument, to the exclusion of other and more practical aspects of the sewage problem, with the result that New York City is today in substantially the same position it was in when the subject of harbor pollution was first taken up in 1903, except that the pollution is greater. The remark of the distinguished English sewage chemist, Samuel Rideal, after making a tour of inspection of New York Harbor in 1912, might have been made today, except that the conditions have been growing worse. "I am surprised," said Dr. Rideal, "that a city claiming to be one of the first in the world should allow such a disgraceful condition of affairs to exist."

Since the last report of the Metropolitan Sewerage Commission, in 1914, when the City was presented with comprehensive plans for sewage disposal works, with their intercepting sewers, tunnels, and other appurtenances, the pollution of the harbor has increased with the growth of population. To the millions of gallons already pouring into the harbor, there has been added an amount of sewage equal to that of Boston, Pittsburgh and Cincinnati combined. Approximately a thousand million gallons empty into the harbor every twenty-four hours from New York City, without taking into account the large contribution from New Jersey cities and the suburbs. The dissolved oxygen has progressively decreased. It has been reported as totally absent on a number of occasions in the best water that could be obtained in the Lower East River and in the Harlem. Every specification of every standard of cleanness and decency that has ever been proposed for these waters has been violated.

The people of New York seem strangely indifferent to the polluted condition of the harbor. They have recently built some of the finest and most expensive hospitals and apartment houses on the shores of the most polluted large part of the inner harbor, namely, the Upper East River, where that fetid stream is joined by the black and malodorous Harlem. Two extensive and expensive marine parks have been laid out and other waterside recreation grounds are contemplated in other parts of the city. Here bathing, boating and fishing will be dangerous, if not repugnant to the senses, unless comprehensive sewage disposal works are built not only for the protection of those particular localities but much larger ones.

To talk about dissolved oxygen in the face of such gross pollution as now affects every part of New York Harbor, therefore, seems academic.

It has much more value in studies of a stream such as the Hudson than of a harbor like New York at the present time. If and when the city and its neighbors on the Jersey side of the line get their heavy work of sanitation attended to, this delicate test will undoubtedly come back to occupy the position of importance which it held when it was originally introduced, but not till then.

Discussion

By Richard H. Gould

New York Harbor is one of the most astonishing of the natural agencies for the disposal of sewage that I know. I never ceased to be amazed by the fact that some ten millions of people can discharge their sewage into its waters and still live on its shores in relative comfort and apparent good health. This is possible only by the combination of a large stream flow from the Hudson River and a fairly rapid and extensive circulation of tidal currents. It is true, of course, that there are places where offensive conditions are now present and other places where conditions are extremely critical. It is apparent to those who are acquainted with the situation that comprehensive corrective measures are even now overdue. Yet I doubt if the majority of the people living in the city know that New York has a sewage disposal problem.

Owing to the complexity of the tidal circulation and flows and many other natural conditions, a quantitative analysis of the elements of pollution and those for natural purification is subject to many uncertainties. The Metropolitan Sewerage Commission, under Doctor Soper, worked on the problem for some eight years. Black and Phelps made a noteworthy report on this matter in 1911 and in the past years Professors Phelps and C. J. Velz have made a further elaborate study. Analyses of the conditions and various studies have been made over a period of some 18 years by the city's engineers, particularly by Mr. Arthur S. Tuttle and the late Mr. Kenneth Allen, and in the past four years by those of us in the Department of Sanitation who are now charged with this problem.

The records show that conditions are becoming progressively worse, with the growth of population in New York State and New Jersey communities. Some accurate method of analysis of the conditions is necessary so that a program of remedial measures can be put into effect that will bring about the desired results.

The most satisfactory method of analysis appears to be along lines similar to those used by Professor Phelps, in which a balance is made between the oxygen demand of the polluting material and the oxygen resources available to meet this demand. Progress is being made in the

improvement of the accuracy of the necessary fundamental data. In computations involving oxygen demand the time of contact of the polluting material with the waters is an important element. Its determination is complicated by the fact that sewage solids under our conditions will settle out on the bottom and remain in the harbor much longer than will the liquid portions. I have not yet satisfied myself that we know the full extent of this oxygen demand.

We are now carrying out laboratory experiments on the relative oxygen demand of the liquid and sludge portions of sewage, and from preliminary indications it appears that it will be necessary to consider these two items separately. The results of a single test, which I am not yet ready to accept as a true picture, would indicate that the oxygen demand of sewage discharged at the Battery when figured separately for liquid and sludge portions might greatly exceed the figure obtained if computations are based on the assumption that the sludge had the same contact time as the liquid portions.

My personal feeling is that in the quantitative studies made so far, the oxygen demands exerted in the harbor have been underestimated and therefore values used for oxygen resources, particularly the oxygen supply from the air, have not been taken at high enough figures.

The practical significance of this question of higher demands due to sludge deposits is very real when we attempt to compute the benefits derived from sewage treatment in the removal of oxygen demand. If this demand proves to be considerable it tends to enhance the apparent benefits secured by preliminary devices for solids removal and may in some cases change our present thought as to the necessity for costly secondary treatment.

Author's Closure

We are indeed fortunate to have had such an excellent and competent discussion of this topic, especially since the author was obliged to advise the listed discussants of his inability to provide an advance copy of his largely extemporaneous remarks. He suggested instead that we each contribute to a symposium from our personal contacts with this problem. I feel that the result has amply justified this method of procedure.

I quite fully agree with Dr. Soper's major contention concerning the position of the dissolved oxygen test. It is not in any sense proposed as a single standard of cleanness for the harbor. It is, however, the best, and, in fact, the only practicable yardstick with which to measure conditions and trends and to relate the actual extent of harbor pollution of all sorts with those many variable factors and influences upon which the actual result depends. Appearances, odors and physical nuisances

in general are after all but the qualitative expressions of a fundamental condition, of which the dissolved oxygen is our present most reliable quantitative index. My personal suggestion would be that during the next few critical years, during which large-scale improvements will be injected into the picture, we will gain information of the greatest practicable value by a considerable enlargement of the present experimental and analytical work of the Department of Sanitation, and it is with gratification that I learn from Mr. Gould that such is the present program.

Mr. Gould's views with regard to the questions both of reaeration and of sludge deposits are worthy of most serious consideration and on the latter point at least I am in entire agreement with him. It is a fact that such deposits develop their maximum oxygen demand in the harbor, whereas the theory of continuous dilution and discharge through the Narrows suggests that about 85 per cent of that demand of the entire sewage flow is thus developed. Theoretically, this should not make any very material difference in the outcome. It is quite possible, however, that there are other considerations that have not yet been taken into account and all matters of this sort, including the fundamental question of the reaeration constant, can be settled much more completely and satisfactorily by a few well planned laboratory experiments than by years of discussion. I have every confidence that with such a program as I understand Mr. Gould has embarked upon, the outcome cannot fail to be completely satisfactory.

Editorial

ELUTRIATION OF SLUDGE

For several years it has been known that digested sludge requires comparatively large amounts of ferric chloride for coagulation prior to vacuum filtration. Based on dry solids content, digested sludge usually requires more than twice as much ferric chloride for optimum filtration as is required for activated sludge, although with optimum flocculation, higher rates of production may be obtained with the digested sludge. In some cases digested sludge required ferric chloride up to 12 per cent of its dry weight for optimum flocculation, and this amounted to a cost of nearly $5 per ton of dry sludge for ferric chloride alone. Because of this prohibitive cost, lesser amounts of ferric chloride were used, with lower rates of filtration.

Research was undertaken at a number of places looking toward the possibility of decreasing the ferric chloride requirement of digested sludge. Various combinations of chemicals were tried, resulting in substantial reduction in amount and cost of ferric chloride. However, apparently the simplest of all procedures, a washing-out of soluble salts, accomplishes an astounding reduction in ferric chloride requirement. For the past two years, Messrs. Genter and Keefer have been studying this procedure, and the results of their admirable research are presented in two noteworthy papers in THIS JOURNAL. The first, by Mr. Genter, dealing with the theoretical and laboratory aspects of the problem, was published in the July, 1934, issue, page 689; the second, by Messrs. Keefer and Kratz, appears on page 845 of this issue. The present long and detailed paper gives the results of the field tests with a small vacuum filter. Prior to either of these papers Mr. Keefer had reported field tests at Baltimore, before use of the principle of elutriation. This paper was published in the November, 1932, issue, page 929.

A comparison of the conclusions before and after the adoption of elutriation is of interest. In the earlier studies, the cost estimates were based on the use of 5.25 per cent of $FeCl_3$ (based on dry solids) with a rate of 7.6 lb. cake (dry basis) per sq. ft. per hour; the present estimate includes the use of 2.5 per cent $FeCl_3$ and a rate of 7.2 lb. per sq. ft. per hour. Thus the ferric chloride requirement is now only 48 per cent of that considered as the minimum amount in the earlier studies.

The cost of ferric chloride was estimated to be nearly three-fourths

of the operating costs in the earlier estimate, but this is now reduced to a little less than half. A comparison of the estimates is as follows:

FERRIC CHLORIDE

Per Cent of Total Costs of Filtration

	Operating Only	Including Interest and Dep.
Former Est.	71	56
Present Est.	49	33

The cost of ferric chloride is still a substantial item, amounting to one-half the operating costs, or one-third the total costs, including fixed charges. It appears doubtful whether this cost can be reduced to any appreciable extent, since 2.25 per cent of ferric chloride is an extremely low dosage, and probably near the irreducible minimum.

The settling period, following dilution with 1 to 2 volumes of water, seems to be quite long. In the Baltimore tests, from 17 to 48 hours of quiescent settling was used. Mr. Keefer states that laboratory tests indicated that 4 to 6 hours would be sufficient; in the estimates of cost, apparently 24 hours was provided. Even with these long settling periods, however, the fixed charges on installed tank capacity should be quite low. The comparatively small volume of elutriate, and its low B.O.D., indicate that there should be no difficulty in disposing of the liquor by re-circulation and re-treatment through the plant. This step, however, might deserve further study, in view of some problems that have arisen in disposition of supernatant liquor from heated digestion tanks. Dr. Fischer's article in this issue (page 956) is of interest as bearing on this problem.

It is unfortunate that the elutriation procedure is of little benefit for pre-treatment of activated sludge or *fresh* settled solids prior to vacuum filtration, but a consideration of the character of these sludges indicates that additional washing would be of no benefit to these already super-elutriated solids. In simple language, the longer sewage solids stew in their own juices, the more benefit will be derived by washing out the "juices."

It is a pleasure to acknowledge the accomplishment of such a fine course of research as has been pursued at Baltimore on this problem. Mr. Genter has a large amount of data in addition to that which has been published, and his data and notes mark the work of a skilled investigator—one with keen powers of observation. The long series of studies of sludge dewatering under Mr. Keefer's direction are likewise noteworthy, extending back to the interesting work on the use of a continuous centrifuge, published in THIS JOURNAL in January, 1929. The problem of the mechanical dewatering of digested sludge has been greatly advanced by the Baltimore studies.

F. W. MOHLMAN

Proceedings of Local Associations

PENNSYLVANIA SEWAGE WORKS ASSOCIATION EIGHTH ANNUAL CONFERENCE

State College, Pa., June 27–29, 1934

The Eighth Annual Conference of the Pennsylvania Sewage Works Association held at the Pennsylvania State College on June 27–29, 1934, State College, Pa., proved to be one of the most successful conferences yet held, with a registration of 115.

The Conference opened on Wednesday evening with a talk by Dr. Willem Rudolfs, "Some of the Newer Developments Abroad," in which he commented upon his observations during his recent trip to Europe. Dr. Rudolfs remarked that some things which we in this country think obsolete or crude are still in successful use in Europe today and that, contrary to much popular opinion, this country is in advance of Europe in sewerage development.

Thursday morning's program opened with a hearty welcome by Professor F. G. Hechler, Assistant Director of the Engineering Experiment Station of Pennsylvania State College, in which he traced the relation of the sanitary engineering profession to our social welfare and told of the College's efforts to assist various groups of workers.

Professor Gordon M. Fair of Harvard University in "The Trickling Filter Fly; Its Habits and Control," presented an unusually complete and scholarly description of the life history and control of this pest. Harry J. Krum, City Chemist of Allentown, led a spirited discussion which developed into a symposium of filter fly experiences.

"Elutriation and Filtration of Sewage Sludges," by Albert L. Genter, Chemist and Mechanical Engineer of Baltimore, outlined in detail the marked reduction in consumption of sludge conditioning chemicals which followed Baltimore City's experiments under Mr. Genter in washing sludges preparatory to conditioning and filtering them.

The discussion by Mr. C. E. Keefer of Baltimore was read by Mr. H. M. Freeburn in his absence. It emphasized the facts developed in Mr. Genter's paper that the filtering properties of sludges are markedly affected by their soluble ammonium derivatives and presented a valuable summary of the practical results and the economic advantages of elutriation as applied in particular to Baltimore.

Frank Woodbury Jones' paper upon "Drying of Sludge on Vacuum Filters and on Open Drying Beds" was a timely presentation of the ad-

vantages and disadvantages of the two methods of sludge drying and precipitated a keen discussion following the presentation by Mr. L. D. Matter of Mr. Wellington Donaldson's written discussion. Mr. Donaldson emphasized the undisputed place held by vacuum filters in dewatering activated sludges, their especial value for chemically precipitated sludges, and their increasing importance in handling conditioned undigested sludges.

A business meeting followed in which the Association elected Roy L. Phillips, City Engineer of Meadville, President; E. B. Wagner, City Engineer of Downingtown, First Vice President; R. R. Cleland of the Pennsylvania State College, Second Vice President; L. D. Matter, Dist. Engineer, Pa. Dept. of Health, Secretary-Treasurer; and J. R. Hoffert, Pennsylvania Department of Health, as Editor. C. A. Emerson of Fuller & McClintock and H. E. Moses, Asst. Chief Engineer, Pa. Dept. of Health, were reelected Representatives on the Board of Control of the Federation.

The Association approved the establishment of a training course for sewage works operators by the Pennsylvania State College, continued its Committee upon the Licensing of Operators, and directed it to submit at the next conference of the Association a draft of a proposed bill providing for their licensing. The usual reports by the Secretary-Treasurer, Auditing and Resolutions Committees were presented and accepted.

Following this came an illustrated talk by H. N. Hess, Chief Civil Engineer, Hershey Estates, upon the "Hershey Sewage Treatment Works and Its Operation" in which the problems raised by a plant handling mainly industrial wastes, high in fat content, were well presented. I. M. Glace, District Engineer of the Pennsylvania Department of Health, led the discussion and brought out the demonstrated value of sludge in improving lawns.

"The operation of the Hanover Sewage Treatment Plant and Its Sewage Ejector Stations," by Borough Manager C. A. Eckbert of Hanover, Pennsylvania, gave a detailed description of a complete treatment works for a medium-sized borough with various industries. R. C. Gorman, District Engineer of the Pennsylvania Department of Health, led the discussion.

On Friday morning a paper by W. L. Stevenson, Chief Engineer, Pennsylvania Department of Health, on "Plant Operation," was read in his absence by H. E. Moses of the Department. Prevention of stream pollution, economy of public funds, protection against complaints and damage suits, and the obtaining of data to show efficiency and help towards future improvements, were the features developed.

In leading the discussion, Harry M. Beaumont, Bureau of Engineer-

ing, City of Philadelphia, accented the need for trained operators of plants involving large capital outlays and filled with potentialities for the public good or harm; the need of an industrial survey to protect the sewers and plant against harmful materials or wastes; the value of cleanliness and attractive appearance of plant as protection against damage suits; the practical value of records; and the importance of constantly keeping before the operator the basic facts in these records.

"Notes on Sedimentation," by Professor L. V. Carpenter, Head, and H. W. Speiden, Instructor, of the University of West Virginia, read in Professor Carpenter's absence by Professor Raymond O'Donnell of Pennsylvania State College, presented in scholarly fashion the various theories regarding sedimentation, their mathematical formulae, the use of model tanks, and a suggested practical formula and bibliography.

F. B. Foote, of Morris-Knowles, Incorporated, Engineers, Pittsburgh, in initiating the discussion, emphasized the limitations of a purely mathematical treatment of sedimentation and referred to the value to be obtained from careful experiments and models; he spoke of the too frequent disregard during actual construction of the principles of theoretical design, the difficulties inherent in small plant design and the increasing attention being paid to proper baffling.

Mr. C. H. Young, District Engineer, Pennsylvania Department of Health, presented the final paper upon "Sludge Digestion at Meadville" and gave valuable data obtained by actual experiment upon the heat losses from temperature controlled digestion tanks and conclusions upon operating experiences with separate digestion plants.

A discussion led by J. R. Hoffert, Pennsylvania Department of Health, brought the Conference to an end.

J. R. Hoffert,
Editor

NEW YORK STATE SEWAGE WORKS ASSOCIATION, NOTICE OF FALL MEETING, ONEONTA, N. Y. OCTOBER 5–6, 1934

The New York State Sewage Works Association will hold its Fall Meeting on October 5 and 6 in Oneonta. The Program Committee has planned an interesting program including an inspection trip to the city's recently constructed sewage treatment plant of the separate sludge digestion type.

Book Reviews

Die Abwasserreinigung. By Hermann Bach. Published by R. Oldenbourg, Munich. Price, Unbound 9.5 Marks, Bound 11 Marks. Second Edition. This volume of 279 pages is the second edition, greatly augmented, of the modest little book first issued by Dr. Bach in 1927. The first edition is unfortunately not well known in America, but the present volume deserves to be included in the library of every sewage works operator, chemist or engineer, primarily in order to present in a brief and clear manner the various types of modern sewage treatment devices and the present status of sewage treatment in Germany. The text is not exclusively devoted to German practice, but many of the chapters contain information of universal value.

Dr. Bach's long experience and authoritative position in German sewage practice are well known, and he has drawn from a rich experience in this work. It is gratifying to note the up-to-date character of the material, and fortunately there is no tedious discussion of the historical development of sewage disposal in Germany. The text is noteworthy for its clear explanation of the various steps in the treatment of sewage.

The book is divided into 34 chapters, some of necessity quite brief. The chapters on the biology of sewage and on the treatment of industrial wastes are noteworthy. There is a chapter on chemical precipitation, but it is brief and general. The chapter on required plant capacities, comprising 21 pages, seems unduly long, in proportion to the other chapters. There is a complete lack of discussion or appreciation of the use and value of the B.O.D. determination, and of the oxygen balance concept in stream pollution. This seems to the reviewer to be the only weak point in this excellent book.

The bound copy is quite attractive in appearance, and there are 120 well chosen illustrations.

F. W. Mohlman.

Reviews and Abstracts

PURIFICATION OF CREAMERY WASTE ON FILTERS AT TWO IOWA CREAMERIES

By W. E. Galligan and Max Levine

Iowa Engineering Experiment Station, Bulletin 115

The Iowa Engineering Experiment Station coöperated with the creameries at Slater and Glidden with a view to determining suitable methods of treating the waste from each of these two plants. Conditions of final disposal of the waste varied at the two places. At Slater the treated waste was discharged into an otherwise dry ditch, whereas at Glidden it was discharged into a municipal sewer system for further treatment.

The Slater Treatment Plant.—The original treatment plant at Slater was constructed in 1928 and operation began in 1929. The plant consisted of a grease trap and grit chamber, an equalizing tank and a trickling filter. The filter, about 0.01 acre in area, was 12 x 36 ft. in plan and 7 ft. deep. The waste was applied by means of a hydro-mechanical device. The original plant, which was unsuccessful for several reasons, was redesigned and rebuilt by the authors in 1929.

Reconstruction of the plant was based upon studies of deficiencies of the existing plant, physical and chemical characteristics of the waste, including volume and variations in discharge rate, and methods used in the creamery in making butter.

To determine the volume and strength of the wastes, the flow of water into and out of each waste-producing unit in the creamery was measured, as was the flow of clear water into and out of each other unit. From a series of such observations the entire flow of the waste and clear water, and their combined flows, were calculated and mass flow curves drawn. The strength of the waste was obtained in a similarly detailed manner. The milk waste proper amounted to 2310 gals. daily, with a weighted mean oxygen consumed value of 1916 p.p.m. and the total flow, to 8107 gals. with an average oxygen consumed value of 546 p.p.m. (a strength about equal to a 1.25 per cent skim milk solution), or 0.42 gal. and 1.48 gal. respectively per pound of butter manufactured.

In redesigning the plant it was impracticable to increase the filter area, although it was known to be inadequate. A more efficient distribution system was installed using Taylor Type D nozzles bushed to $\frac{5}{8}$

inch in conjunction with a primary and secondary dosing tank. Storage capacity was added to the total of 1650 gallons below the invert of the inlet pipe.

The reconstructed plant was operated from Sept. 6, 1929, until May, 1930, with the exception of a 6-weeks' shut-down for pump repairs. The storage tank was not large enough to hold all of the day's waste and it was necessary to by-pass a considerable amount of clear water. The filter was operated at 860,000 gal. per acre per day, later increased to 1 million gals. per acre per day. The butter production continued to increase and it was necessary to by-pass more and more clear water, thus increasing the strength of the waste as applied to the filter. In the early spring the cinder bed began to clog badly. Spading was resorted to, but was ineffective after a time. Chlorine (30 p.p.m.) was added to the cinder bed for relief of the clogging but was ineffective. In May, 1930, the cinder bed had become so badly clogged that it was decided to remove the cinders and replace them with crushed quartzite. This was done in August, 1930. The cinders had disintegrated greatly, but the amount could not be determined because no screen analysis had been made when they were placed in the filter.

After the filter was changed to quartzite, operation of the plant was satisfactory for some time, but as the load continued to increase the filter again began to clog. A portion of the milk waste was by-passed and chlorinated, resulting in satisfactory treatment of all the waste until the flow further increased.

In 1928, the year the filter was built, the creamery produced 681,482 pounds of butter. In 1930 when the quartzite was put into service, 1,182,122 pounds of butter were produced. In 1931 the production increased to 1,657,939 pounds, resulting in more waste than could be handled by the filter. The excess was chlorinated and by-passed. The maximum daily production during the summer of 1931 rose to more than 10,000 pounds. Assuming the amount of waste to vary in proportion to the pounds of butter produced, this maximum day resulted in an equivalentt of 9,130 gals. of 2 per cent skim milk, which if dosed on a 0.01 acre filter in 12 hrs. would equal a rate of 1,826,000 gals. per acre per day.

The distribution system worked well except when growths were allowed to form in the dosing tanks and slough off into the pipe system. The distributing pipes themselves never showed a tendency to clog. The grease trap and grit chamber, though not large enough to remove properly the solids in the waste, did remove matches, grease, bottle caps, grit and brush bristles, which would have caused pump clogging. When the load on the filter was less than 860,000 gallons per acre per day and the average concentration not over 2 per cent skim milk solution, the

filter worked satisfactorily, reducing the oxygen consumed value of the waste more than 80 per cent. As the flow rose to about 1,000,000 gals. per acre per day, it became evident that the waste could not be handled without greatly increasing the filter area. The plant continued to operate until the quartzite filter clogged badly and mechanical trouble with pumping was experienced. Then operation was stopped, as arrangements could not be made to enlarge the filter and construct the proper grit, grease and storage tanks. The experiences at the Slater plant demonstrated, however, that plain sedimentation followed by a trickling filter was suitable for purification of creamery wastes if not overloaded.

The Glidden Treatment Plant.—The town of Glidden has a population of about 900 and the sewage is treated with an Imhoff tank and intermittent sand filter. The treated creamery wastes are discharged into the municipal sewer.

A "stream-flow" type of activated sludge plant had been built to treat the waste from this creamery, but had proved unsatisfactory, because of inadequate pumping, which caused poor circulation and sedimentation of solids in the tank. After several unsuccessful attempts had been made to alter this plant so that it could be operated satisfactorily, it was decided to abandon it and change the method of treatment to filtration.

Studies made of the different waste flows over a period of three days showed that 3 gals. of water were used per pound of butter produced, of which 0.59 gal. was milk waste and floor washing. Based on an estimated maximum daily production of 9,400 lbs. of butter, it was estimated that 5,550 gals. of milk waste were produced, with a probable oxygen consumed value of 605 p.p.m., to be treated with the total flow of 28,200 gals.

Arrangements for by-passing the clear water were made and the plant remodeled to consist of a combined grease trap and grit chamber, a pump sump and a quartzite filter. The combined grease trap and grit chamber was designed for an average detention period of 4 hours and was baffled to effect better removal of the solids. The pump sump was made large to give flexibility in operation in case it were found advisable to increase the storage period. The pump discharge from the storage tank entered a small orifice box above the primary dosing tank. The orifice box was provided with an overflow back to the pump sump to maintain a constant head on the orifice. A secondary dosing tank was used to secure good distribution. The distribution system consisted of a 4-inch header with 2-inch laterals and ⅞-inch Taylor Type B nozzles bushed to ⅝". The filter was 7 ft. deep and about 0.0087 acre in area, consisting of crushed quartzite ranging from 1 to 2½ inches in size. Underdrains were spaced 2 ft. on centers and a gallery was

provided on each end of the filter to afford good ventilation. The filter and storage tank were enclosed in a building, but the combined grease trap and grit chamber had only a trap door to serve as a cover.

From June, 1930, to July, 1932, the plant was visited at irregular intervals. In addition to grab samples taken during these visits, a series of composite samples was taken over a four or five day period each summer. During these periods of composite sampling the waste was being applied to the filter for 8 to 9 hrs. daily at a rate of 810,000 to 1,000,000 gals. per acre per day. This long rest period was not necessary and the filter could have handled efficiently two to three times as much waste if it were distributed over a period of about 20 hrs. The B.O.D. of the influent averaged approximately 1,100 p.p.m. and of the effluent, 82 p.p.m., which was considerably less than that of the domestic sewage of the community. The reaction of the applied waste was generally not far from neutrality but became distinctly acid when stored anaerobically. The filter effluent, however, remained alkaline on storage, indicating that it would not adversely affect the reaction in an Imhoff or septic tank. The production of nitrates was very marked except for the first period in June, 1930, before the filter was properly ripened.

Summary.—The selection of a method of treatment of creamery wastes should be adapted to the local situation, with particular regard to the degree of purification necessary and the characteristics of the waste in question. A preliminary survey and study of local conditions is indispensable to proper design. Particular attention should be paid to details of plant operation affecting flows, and to the volume and strength of flows at intervals throughout the plant operating day.

Every possible effort should be made to reduce the concentration of milk waste constituents leaving the creamery. Staggering the discharge of different waste-producing units is often of advantage in this respect.

The degree of purification necessary is dependent upon the ultimate disposal of the purification plant effluent. If the effluent is discharged into a dry ditch, it would be essential to produce a highly purified effluent, having a low oxygen demand and preferably well nitrified. It might be desirable in some cases to chlorinate the effluent, to retard or prevent growths in the dry ditch. Where the effluent is to be discharged into a municipal sewer system, complete purification is not necessary; merely elimination of most of the acid-producing constituents. This may be accomplished without danger of injury to the municipal sewage treatment plant if the creamery waste is applied to a trickling filter at a rate of 1,000,000 gals. per acre per day. Double this rate might be feasible, but there would be some danger of reducing the efficiency of the filter by clogging.

R. S. SMITH

HOURLY LOAD VARIATIONS AS A FACTOR IN SEWAGE TREATMENT PLANT OPERATION

By Elson T. Killam

Water Works and Sewerage, 81, 7 (July, 1934)

The combined effect of the variations normally occurring both in the strength and in the volume of flow of the sewage arriving at a treatment plant during the different hours of the day is a controlling factor in the efficiency of plant operation.

It has been found that even in a large system where the variations are comparatively small in proportion, the load, based on suspended solids and flow variations, for the maximum 2-hour period was 14 times that of the minimum period. In a comparatively small system where the variations were relatively marked, the load for the maximum 2-hour period was 1,800 times the load for the minimum 2-hour period, based on suspended solids and flow variations.

Among the more important factors influencing the relative load curves in each specific case, are the following:

(*a*) The mileage involved in the collecting system and the sewer grades;
(*b*) The amount of infiltration;
(*c*) The habits of the contributing population with regard to hours of rising and retiring;
(*d*) The industries contributing waste to the system and their practice as regards hours of operation.

The variations in the strength of sewage, rate of flow and load by 2-hour periods over a 24-hour day are given for two representative sewer systems. One, the Peachtree Creek system of Atlanta, Ga., is an extensive collecting system of large combined sewers with a relatively high rate of infiltration. The other, Shoal Creek system of Decatur, Ga., is a relatively small separate system serving a strictly residential district and with a low rate of infiltration. In the Peachtree system the maximum rate of flow was 138 per cent and the minimum 70 per cent of the daily average while the maximum concentration of suspended solids was 167 per cent and the minimum 22 per cent of the daily average. In the Shoal Creek system the maximum flow was 165 per cent and the minimum was 35 per cent of the daily average. Suspended solids in this smaller system varied from 223 per cent to 0.5 per cent of the average. The hourly variation in load, resulting from the combined effect of these two variables, ranged from 190 per cent to 14 per cent of the daily average for the Peachtree system and from 280 to 0.16 per cent of the average for the Shoal Creek system. The trend of the B.O.D.

content was very similar to the variations in suspended solids. It was found that 60 per cent of the total daily load arrived at the plant in an eight hour operating period and 90 to 95 per cent within 16 hours operation. This concentration of the greatest portion of the daily load within a relatively short time is important as affecting the efficiency and cost of treatment in various ways. It is a controlling factor in fixing design capacities. The period of extremely light load affords a rest or recovery period which may be extremely beneficial to activated sludge or trickling filter plants. At smaller plants, it may be entirely feasible to provide attendants only during the period of heavy load, thus substantially reducing the cost of operation.

Conclusions

1. It is evident that sewage treatment plants do most of their work during only a portion of each 24-hour day.

2. In biological plants the low loading periods allow the process to recuperate if overtaxed during the heavy duty periods.

3. In many instances economy of performance might be had by patterning the operation of the plant to meet the schedule of load requirements only.

4. In chemical treatment processes the cost of treatment can be materially and logically decreased by lessening or discontinuing the use of chemicals during periods of light plant loading.

R. S. Smith

MODERNIZING AND ENLARGING AN ACTIVATED SLUDGE PLANT

By Ernest W. Whitlock

Engineering News Record, 112, 733–737 (June 7, 1934)

The original plant at Hagerstown, Maryland, built in 1925, consisted of coarse and fine screening, grit chambers, mechanical aerators for activated sludge, final settling tanks and sludge drying beds with disposal of sludge on city owned farm land. Increased sewage flow and unsatisfactory results led to reconstruction and enlarging of the plant, completed in May, 1933.

The design data for the new plant, on a basis of 4 m.g.d. from 40,000 connected population in 1945 are as follows:

Aerated grease separation tanks, minutes average detention	4.0
Preliminary sedimentation, hours average detention	1.0
Aeration tanks (sewage plus 25 per cent return sludge), hours average detention	6.0
Air provided at average flow c.f./gal.	1.2
Final tanks, gals. per sq. ft. daily	800
Dry solids in sewage, lbs. per cap. per day	.2
Per cent mixture in mixed sludge	97
Minimum sludge filtering rate dry sewage solids/hr.	1.0

Flows in excess of 8 m.g.d. are to be by-passed and those between 6 and 8 m.g.d. settled only. A new overflow chamber was constructed but no changes were made in the screening arrangement. The old grit chamber was reconstructed with a new trough bottom, a single row of diffuser tubes down the center, and longitudinal wooden baffles with V notched wooden timbers on top. Grease is forced into the side compartments through the bottoms of the notches. The sewage level is controlled by an adjustable outlet weir. The two preliminary settling tanks are rectangular, with longitudinal sludge scrapers, a perforated overdur inlet baffle, and grease skimming trough. Excess activated sludge is returned to these tanks, either or both of which may be used. The aeration tanks are arranged in two batteries of three each. Either or both of the batteries may be used, with the three tanks used in series or in parallel, or any or all of the six tanks may be used in parallel. Each aeration tank is 129 feet long, 16 feet wide and 15 feet deep and has a double row of diffuser plates, equal in area to 10 per cent of the tank area, arranged for spiral flow. Four transverse wooden baffles are installed to prevent short circuiting. The final settling tanks are 50 feet square by 10 feet deep and are equipped with spiral scraper mechanism for sludge removal. Air is supplied at from 7–9 lbs. pressure by duplicate 3-stage horizontal centrifugal blowers.

The mixture of undigested fine screenings, primary and activated suldge, after conditioning with lime and ferric chloride is dewatered by vacuum filters to 80 per cent moisture content and is used without nuisance on city owned farm land. Conditioning with lime and macerated paper was tried but not found satisfactory.

A rather complete table of operating data for the month of March, 1934, is included.

The cost of reconstruction, excluding the price of land was $80,000 per m.g. of capacity. Operating costs will approximate $1.15 per capita per year or $35.00 per m.g. of sewage, about $10.00 of the latter being sludge filtering costs.

R. W. Kehr

RATIONAL STORM DRAIN DESIGN PRACTICE IN LOS ANGELES

ANONYMOUS

Public Works, 65, 38–40 (June, 1934)

The rational method is used at Los Angeles in designing storm sewers, inlets and catch basins. Where $Q =$ the discharge in c.f.s, R, the maximum intensity of rainfall in inches per hour for a given time of concentration, A, the area in acres, and C, the coefficient of imperviousness, the equation $Q = CAR$ would hold. The value of C depends upon the percentage of impervious area such as roofs, pavement, etc., in the tributary area, and on the length of rainfall. Percentages of imperviousness which have been assumed in Los Angeles from experience and observation are as follows:

Park areas and large estates	pervious
Suburban residential areas	30% impervious
Urban residential areas	50% impervious
Apartment house areas and suburban business	70% impervious
Commercial areas	90% impervious

A graph is given from which, with an assumed percentage of imperviousness and the minimum time of flow (t) from the furthest point in the area, can be obtained values of C. When (t) is less than about 20 minutes for pervious areas and 10 minutes for areas more or less impervious, the maximum runoff would occur at a time greater than (t) and three tables are given with modified values of C to correct for this. A graph of Los Angeles rainfall intensity curves made up from 20 years of rainfall data is also given. For business districts, maximum rainfall intensities during a 15-year period are used in the computation, while for sump areas, a 25-year curve is used and for other areas, a 10-year curve, generally.

Two other tables are given, one listing the inlet time and imperviousness assumed with gutter grades of 3 per cent or less and the other, inlet times and imperviousness for gutter grades of over 3 per cent. A sample calculation of the discharge from a drainage area is given.

R. W. KEHR

SEWAGE DISPOSAL AT STOCKPORT

ANONYMOUS

The Surveyor, **86**, 3–5 (July 6, 1934)

A new bioaeration sewage treatment works, involving an expenditure of £250,000 has just been completed for the County Borough of Stockport, England. The total area served is in excess of 7,000 acres and the total population contributing is estimated at 130,000. The sewage provided for amounts to 6¼ m.g.d., including all of the trade effluents of the town which equal rather more than one quarter of the total dry weather flow.

After full investigation the late Mr. John Haworth reported that the bioaeration process, of which he was the originator, was applicable to Stockport sewage and this method of treatment was finally adopted. The main features of the new plant include a new pump house, three detritus tanks, lime house and mixer, eight precipitation tanks, five aeration units with appurtenances, forty-five final settlement tanks, four sludge digestion tanks, five acres of sludge beds and new laboratory.

Aeration Units.—Each unit is 266 × 143 ft. in plan, divided by thin reinforced concrete walls 5 ft. high into one continuous channel 5 ft. 3 in. wide and about 7,000 ft. long. The capacity at 4 ft. sewage depth is 0.9 m.g. although in practice a depth of from 3 to 3.5 ft. has been found more economical. The sewage is propelled through the channels by 26 paddle wheels 9 or 10 ft. in diameter mounted on line shafting and driven from a central power house through reduction gears by 50 h.p. motors. In four of the tanks these wheels are located in the mid-length of the channel runs while in the fifth tank they are located at each end with a view to improving agitation. Each unit can treat 1.15 m.g.d. of dry weather sewage or three times this amount of storm flow.

Sludge Disposal.—To accommodate the large volume of sludge four digestion lagoons with earth banks 14 ft. high are provided with a total capacity of 4¾ m.g. or 5.63 cu. ft. per head of population served. Sixteen underdrained drying beds receive the digested sludge. Further dewatering facilities are provided to condition the sludge for fertilizer. A general plan of the works and several photographs accompany the article.

J. K. HOSKINS

SEWERAGE AND SEWAGE DISPOSAL OF SITTINGBOURNE AND MILTON *

By G. T. Cotterell

As a result of the amalgamation of the urban districts of Sittingbourne and Milton in 1930 and the inclusion of a considerable rural, unsewered area, it became necessary to redesign the existing sewerage systems and provide adequate treatment facilities. It was determined that one central works located on Church Marshes would be more economical in maintenance and operation than enlargement of the three existing plants. Gravity flow to the new site would likewise reduce the amount of sewage to be pumped. Accordingly the new scheme of sewerage provides for a future population of 36,000 and a dry-weather flow of 0.9 m.g.d., while the disposal works, which can be readily enlarged, is designed for a population of 27,000 and a dry-weather flow of 675,000 g.p.d.

The activated sludge method was selected because the capital cost was cheaper than that for percolating filters, the efficiency of treatment greater, and pumping could be eliminated. The plant, which cost approximately £100,000, comprises:

1. Inlet chamber, screens and grit channels.
2. Grease and oil interceptor.
3. Three sedimentation tanks of the Imhoff type, vented and operated in parallel.
4. Activated sludge plant, including aeration and reaeration channels of the diffused air type and settling tanks.
5. Two sludge digestion tanks each of 19,171 cu. ft. capacity equipped with gas collectors, which latter discharge to:
6. Gasometer of 5,000 cu ft. capacity.

Operation.—A detention period of seven hours is provided in the primary sedimentation tanks, which is considered ample. Trouble has been experienced with trades waste which has upset the operation of the works. The sludge digestion tanks are operated at present in series as primary and secondary tanks, although they can be arranged to operate in parallel for single digestion. The gas produced has amounted to as much as 1.14 cu. ft. per capita per day and has a calorific value of about 700 B.T.U. It is generated more freely at a temperature of about 75° F. and accordingly hot water coils have been installed around the inside of both digestion tanks. The gas is used for power to drive the air com-

* Paper presented at joint meeting of the Southeastern and Metropolitan Districts of the Institution of Municipal and County Engineers on July 14, 1934, and extracted, together with discussion, in *The Surveyor*, **86**, 53–4, 57–8 (July 20, 1934).

pressor plant, employing an engine which consumes 21.2 cu. ft. per B.H.P. per hour.

The digested sludge is dried on underdrained clinker beds having a total area of 4,115 sq. yds. The drainage liquor, together with the digestion tank supernatant, is discharged to the outfall sewer. The digested sludge dries readily, is odorless and does not attract flies. It is hoped to dispose of it to farmers for fertilizer.

J. K. Hoskins

REVOLVING DISTRIBUTORS FOR TRICKLING FILTERS

By W. Allen Darby

Public Works, 65, 37–38 (July, 1934)

Revolving, reaction propelled distributors for trickling filters consist of a fixed steel or cast iron center column with a bearing on top which supports the rotating hub to which the arms are attached. The arms are braced vertically and laterally with adjustable cables. Settled sewage from a feed pipe connected to the base, flows upward through the hub into the arms and out through ½ to 1 inch holes or bushed nozzles, the reaction of its discharge through these holes producing rotation. A seal, either liquid or packed, is provided between the rotating hub and fixed column. The liquid types are of oil, water or mercury and should be protected against excessive surges and in case water is used, from freezing in cold climates. Complete coverage of the bed is obtained by frequent holes in the rotating arms or by less frequent and larger holes with deflectors. In either case, the holes are staggered so that different ring areas are covered by each arm. The holes are usually 6 to 12 inches above the filter stone. At the outer end of each arm, a quick opening dump gate is provided for flushing and each arm may be provided with a small drain plug located near its middle to provide drainage during cold weather. Where winters are severe it may be necessary, with small plants, to drain the feed line also after each dose.

A dosing tank and automatic siphons are usually used. The siphon is designed to discharge at a rate equal to the maximum flow, with a minimum of 12″ and preferably 18″ to 30″ head. The drawdown in the dosing tank should not be less than 6″ due to difficulties of siphon adjustments nor more than two or three feet due to undesirable variation in distributor discharge rates.

Using deflector nozzles two arm rotary distributors have proven practicable, since the numbers of discharge holes necessary for good distribution may be kept down.

Where sewage is pumped following preliminary sedimentation the dosing tank may be eliminated and settled sewage pumped direct to the distributor, but a packed seal is desirable in this event. To prevent freezing, the feed line in this case can be drained back to the pump well.

When the maximum rate of flow greatly exceeds the average, the distributor system may be designed to care for an amount less than the maximum flow, but freeboard must be provided in the dosing tank to care for the sewage backing up when the distributor becomes overloaded.

R. W. KEHR

DRYING AND INCINERATION OF SEWAGE SLUDGE

BY ALDEN E. STILSON

Public Works, 65, 53–54 (June, 1934)

This article is a continuation of one by the same author appearing in the May, 1934, issue of *Public Works*. The addition of macerated paper to sewage increases the cost of dehydrating the sludge and in addition, the resultant sludge has a lower fuel value making incineration more difficult.

The following notes are given on the design of screenings incinerators: 1400° to 1600° F. temperature in firing chamber (ash shags readily above 1600° F.); the combustible must be kept free from ash as far as possible, requiring agitation or stoking for complete utilization of fuel values; the ash is highly refractory and acid and is very light; a minimum of 18 pounds of air per pound of ash and moisture free combustible are probably necessary.

The following data are given for the design of sludge incinerators: 1600°–1800° F. temperature in the firing chamber with a heat release of 16,000 B.T.U. per cubic foot per hour, and utilization of radiant heat to burn out reluctantly combustible material in the ash; continuous stoking in small quantities and oil removal; acid refractories of high densities containing low quantities of native basic fluxes; primary and secondary air under definite control, quickly regulated; limited time of storage for the dried sludge; combustion as near as possible to the point of introduction of the material, with ample secondary combustion and settling chamber; positive means for removal of fly ash before discharge of waste gas to chimney; different sludges may require different details of design.

In a discussion of both this and the preceding article, Willem Rudolfs and W. H. Baumgartner, in the July, 1934, issue of *Public Works*, point out the difficulties of adapting mechanisms used in other industries to

the drying and incineration of sewage solids. They consider the use of large quantities of low temperature air uneconomical and have found appreciable odors given off by fresh solids at the suggested drying temperature of 125° F.

R. W. KEHR

STORM SEWER INSTALLATION BY RELIEF WORK

BY KNOWLTON L. BRODE

Public Works, 65, 31 (June, 1934)

A total length of 1,326 feet of 42" storm sewer was laid as a relief project, using hand labor at a cost of $2.10 per foot for excavation and backfilling and 9.3 cents per foot for pipe handling. The average trench depth was 6½ feet. Corrugated metal pipe with paved invert was used throughout. The pipe was furnished in 14, 18 and 20 foot sections and required no special equipment for handling. Connections were made with heavy bands tightened with a small hand wrench.

R. W. KEHR

A CONTRIBUTION TO THE TREATMENT OF DISTILLERY WASTE WATERS

BY O. ACKLIN, K. BRAM AND M. ZURCHER

Tech. Hyg. (Suppl. to Schweiz. Z. Strasswesen), 3, 38, 1933. (British Water Pollution Research—Summary of Current Literature, VII, 7, Abstr. 877.)

A plant treating waste waters from a fruit distillery in Switzerland is described. The wastes, discharged at a rate of 150 cubic meters daily, contain much solid matter and have a pH of 3.0–3.5, a temperature generally above 80° C. and a residue on evaporation of 20–22 gms. per liter, 5 per cent of which is mineral matter. Treatment involves neutralization in a mixing chamber by automatically controlled doses of a 1.2 per cent mixture of lime and water and filtration through gravel and sand. Sludge is left to dry during the summer and when removed may be used as fertilizer. Treated wastes are almost clear and odorless and have a pH of 7.0–7.3 and a residue on evaporation of 8–10 gms. per liter, 70–78 per cent of this being organic matter. Experiments are being made on further treatment of the effluent with peat. The container for the lime solution has been coated with "Emerit," which has proved resistant to corrosion by alkali. Details are given of the calculations of capacities and diagrams of the plant.

H. W. STREETER

THE TREATMENT OF SEWAGE ON BACTERIAL FILTERS

By R. Gaultier

Tech. Sanit. Municip., 29, 13, 1934 (British Water Pollution Research—Summary of Current Literature, VII, 7, Abstr. 866).

The author discusses the processes of a trickling filter, the disadvantages of preliminary septic tank treatment and the importance of pre-treating the sewage in two-story tanks or settling tanks with frequent sludge removal. He then discusses investigations on the operation of trickling filters. As the filter matures, the time of retention of sewage in the filter increases with the growth of the bacterial film on the filtering medium. The purification achieved is directly proportional to the volume of this film and the time of contact and permissible loading can be calculated from the volume of the film. If the sewage is fresh and well oxygenated the amount of oxygen thus introduced nearly suffices for the processes in the filter and the main purpose of ventilation is to get rid of the products of combustion, notably carbon dioxide. Temperature is an important influence; the active bacterial feeder *Paramecium* multiplies 8 times as rapidly at 30 degrees Centigrade as at 10 degrees. Calculations based on filter operation show that an active filter at 15 degrees Centigrade can destroy 5 kg. of organic matter per cubic meter of film per day. Curves are given showing for different sizes of media the volume of film formed, the amount of air required for ventilation and the time of contact required for sewages of different concentration and also showing the influence of temperature on the development of micro-organisms.

H. W. Streeter

EFFECT OF BOTTOM VENTILATION ON PURIFICATION BY AN EXPERIMENTAL TRICKLING FILTER

By Max Levine and H. E. Goresline

Iowa Engineering Experiment Station, Bulletin 116

Introduction.—Trickling filters are generally recognized to be oxidizing devices which must be so constructed as to permit adequate aeration for satisfactory results. Authorities differ as to how this aeration and ventilation are obtained, many holding that they are maintained by the downward movement of the sewage through the stone bed, and others, that adequate provision for ventilation from the bottom or even forced bottom aeration, is desirable if not essential. This report deals with the

results obtained in treating skim milk solutions on small experimental trickling filters in which natural bottom aeration could be provided or completely eliminated at will.

Construction and Operation of Filters.—Each of the two filters used in this experimental work was 2 ft. square and 6 ft. deep, and constructed of galvanized sheet iron. The supports for the filter media consisted of two-foot lengths of one-inch galvanized iron pipe laid across the bottom of the filter with about one-inch openings between them. A pyramidal hopper provided with a water sealed trap outlet was attached to the filter below this grating to serve as a collector for the effluent. Two 1½ inch ventilating ports which could be opened or closed as desired were inserted in the sides of the hopper to afford a method of controlling bottom aeration.

The filter media consisted of about 6 inches of quartzite (2 to 3 inch size) placed directly upon the pipe grids and 5½ foot of carefully washed clinker, 5 feet of which was ⅝ to 2 inch and the upper 6 inches 2 to 4 inch in size, which was intended to reduce the washing effect on the filter surface. Dosing was accomplished by a tipping bucket which emptied into a perforated metal tray covering the entire surface and supported about 6 inches above the surface of the clinker.

The skim milk waste was applied at a rate of 840,000 gallons per acre per day for 14 hours daily, or a dosing rate of approximately 500,000 gallons per acre per 24 hours. The long rest period of 8 to 10 hours simulated conditions customary in small creameries. The dosing cycle was short, being about four minutes.

The filters were placed side by side in a basement room where there were no marked fluctuations in temperature and were operated simultaneously. A ventilating fan kept the air in motion, but there were no marked drafts; hence air movements about the surface of the filters were more nearly approximate to those of an enclosed filter installation than to those existing in open outdoor filters.

For two weeks the filters were ripened on a 1 per cent skim milk solution with bottom vents open. At the end of this period the effluents of both filters were of similar composition containing 0.14–0.17 p.p.m. of ammonia, 11.9–13.2 p.p.m. nitrate and 3.3–3.4 p.p.m. of organic nitrogen. After ripening, the vents in one filter were closed while those in the other were left open and each filter was subjected to several cycles of two to four weeks each with alternately open and closed bottom vents. During this test period the filters were dosed with a 2 per cent skim milk solution. This raw waste varied somewhat from day to day, but was very much more constant than the sewages ordinarily applied to filters and averaged 923 p.p.m. B.O.D., 103 p.p.m suspended solids, 82 p.p.m. organic nitrogen and an average pH value of 6.7.

Results.—The results obtained with the two filters were strikingly similar. The ammonia content of each filter rose considerably after closing the bottom vents and dropped to relatively low figures when bottom ventilation was renewed. Organic nitrogen in the effluent varied correspondingly. Nitrate in the effluent of one filter varied from 1 to 3 p.p.m. during several cycles with no bottom ventilation and rose to 12–25 p.p.m. with the ventilating ports open.

It was found that a filter operating with no bottom ventilation clogged more quickly than one with bottom ventilation. Washing or chlorinating a clogged filter was of little use if the bottom vents remained closed. The filter operating without bottom ventilation generally had an effluent with an acid reaction and a very high B.O.D., whereas the one with the air vents open had an alkaline effluent with a low demand. Opening the bottom vents on a filter that had been operating for several weeks without bottom aeration was not in itself sufficient to permit recuperation within a week. However, providing bottom ventilation and washing the filter resulted in rapid complete recovery of the unit's purification power.

Conclusions.—The experiments show definitely that elimination of bottom ventilation resulted in a rapid decrease in the purifying efficiency of the filter as shown by marked reduction in nitrates, increases in ammonia, organic nitrogen and acidity, and a remarkable increase in the biochemical demand of the effluent.

Elimination of bottom ventilation was quickly followed by severe clogging of the filter. Opening the bottom vents, after the filter became clogged, did not result in very rapid recovery until after the filter was washed.

With the filtering media employed and the high concentration of waste applied, bottom ventilation was essential to efficient functioning of the filter. With no bottom ventilation, the filters rapidly decreased in efficiency in spite of the 8–10 hour daily rest period (during which time the filters were empty and there was ample opportunity for diffusion of air through the top) and neither washing nor chlorinating the filters improved the effluent as long as the bottom vents remained closed.

RUSSELL S. SMITH

THE NEW EDGERTON SEWAGE WORKS HELP CLEAN UP ROCK RIVER VALLEY

By W. G. Kirchoffer

The American City, 69, 61–62 (July, 1934)

The Edgerton, Wisconsin sewage disposal plant is a separate sludge digestion-sprinkling filter plant and consists of the units common to plants of this type—namely, bar screens, primary settling tank, sprinkling filter, secondary tank, sludge digestion unit, and various pumping appurtenances.

The clarifiers are equipped with Link Belt sludge collectors. The sprinkling filter is ninety feet in diameter and eight feet deep. It is fed by means of a revolving arm. Gas from the digestors is collected and used for heating.

The plant was constructed at a cost of $28,234.46.

E. Hurwitz

OPERATING RESULTS OF THE NEW HAGERSTOWN, MARYLAND, SEWAGE PLANT

By H. E. Rhodes

Municipal Sanitation, 5, 199–200 (June, 1934)

The Hagerstown sewage treatment plant is designed to settle 8 m.g.d. and aerate 6 m.g.d. The sewage flows to the plant by gravity, passing first through coarse bar screens, then fine screens. From the fine screens it flows to a grease removal tank and then to the primary settling tanks. There are two of these, each with a capacity of 9000 gallons and a detention period of one to one and one half hours. They are equipped with Link-Belt sludge collectors. From the primary settling tanks the sewage flows into six aeration tanks each with a capacity of 226,000 gallons and equipped with a double row of diffuser plates. The aeration period is six to eight hours. There are two secondary settling tanks equipped with Hardinge spiral scrapers. Excess sludge is wasted to the primary settling tanks.

Sludge is dewatered on a Wright vacuum filter using ferric chloride as a conditioner.

Operating data for the first six months are given in the following table:

Average flow ..... 2,610 m.g.d.
Sludge returned ..... 40 per cent of flow
Average amount of air used ..... 0.95 cu. ft. per gallon
Average suspended solids retained in plant, dry (exclusive of coarse and fine screening) ..... 3,118 lbs. per day
Average dry wt. of sludge and fine screenings removed daily .. 4,170 lbs.

	Screened Sewage	Final Effluent
Suspended solids	159 p.p.m.	17 p.p.m.
B.O.D.—5-day	134	19
Oxygen consumed	76	22
Organic nitrogen	3.38	1.07
Ammonia nitrogen	13.26	5.68
Nitrite nitrogen	0.55	1.60
Nitrate nitrogen	0.84	2.94
Dissolved oxygen	3.8	3.4

E. HURWITZ

SANITATION IN SHANGHAI, CHINA

BY ISADOR W. MENDELSOHN

Municipal Sanitation, 5, 190–193 (June, 1934)

Sewage from the International Settlement at Shanghai is disposed of in three treatment plants; the Western District with an average dry-weather flow of 1.608 m.g.d., the Eastern District with a flow of 1.824 m.g.d., and the Rifle Range works with a flow of 0.122 m.g.d.

The eastern and western works apparently are of like design, consisting of six sedimentation basins with a total capacity of 211,824 gallons; aeration tanks are arranged in four units of four channels each with a total capacity of 2 m.g. and sludge drying beds.

Most of the important buildings in the International section are connected to the sewerage system. Those not connected are served by night soil collection. Almost the whole of the Chinese section is served by night soil collection.

The article also contains a detailed description of the waterworks systems in both the International Settlement and Chinese sections.

E. HURWITZ

A SEWAGE DISPOSAL PLANT DESIGNED FOR ECONOMY

By Robert Cramer

The American City, **49**, 78–79 (June, 1934)

The Fort Atkinson sewage disposal plant serves a population of 6,000 people and is designed to handle the flow from a population of 9,000 plus industrial wastes that come from a slaughter house, sausage factory and several machinery manufacturing plants. At present the plant is treating 0.42 m.g.d.

The plant provides complete treatment by activated sludge. All the settling tanks, primary and secondary, are rectangular in shape and equipped with Jeffrey sludge collectors. Aeration is accomplished by means of Link Belt straight line aerators. The digestor is equipped with Downes floating cover and gas collectors. Digested sludge is dried on sand beds and used in the city parks as fertilizer. The supernatant digestor liquor is dosed with lime in a tank arranged especially for this purpose and then returned to the plant influent.

The digestor gas is used to operate a gas engine generator so arranged that it floats on the public service current supply. The arrangement is such that whenever the rate of gas generation exceeds the rate at which the engine consumes gas, the surplus accumulates in a holder until the pressure acts against a throttle valve, opening it wider, thus feeding more gas to the engine which in turn produces more power and decreases the amount drawn from the public service supply. When the rate of gas production decreases the reverse occurs. It is claimed that through this arrangement the greatest possible use is made of the gas with definite saving in operating costs.

E. Hurwitz

SOME RECENT DEVELOPMENTS IN SEWAGE TREATMENT PRACTICE

By Wellington Donaldson

Municipal Sanitation, **5**, 11–12 (Jan., 1934)

At the present time, dominant interest in sewage treatment seems to be centered around chemical precipitation processes. These processes have two distinct fields: one where the process is self-contained and another where it is used as an auxiliary to improve existing biological processes.

Large scale operation of plants using chemical precipitation as a complete process are found at Winston-Salem, N. C., where 1,500 to 2,500 pounds per million gallons of lime are used. Excellent clarification is obtained but removal of organic matter as measured by B.O.D. is only approximately 65 per cent. The installation at Dearborn, Michigan, uses lime, ferric salts, and paper pulp and obtains a removal up to 70 per cent. Other installations are at Providence, R. I., where lime and chlorine are used to treat some 35 m.g.d. as a temporary measure pending construction of an activated sludge plant and at Birmingham where chlorinated copperas and lime are used.

Experimental installation of complete treatment by chemical precipitation are the (1) Guggenheim experiment at the North Side Treatment Works in Chicago. Ferric sulphate and lime followed by filtration through a zeolite filter are used. Approximately 83 per cent removal of B.O.D. is obtained in the primary treatment which is increased to 90 per cent by the zeolite filter; (2) the Streander experiment in Philadelphia employing ferrous sulphate and lime in which compressed air is used for mixing and oxidation, followed by rapid sand filters; (3) the Lewis experiment at Atlanta in which ferric chloride, lime, Cottrell dust and ferrous sulphate are used followed by rapid sand filters.

The use of chemicals as an adjunct to existing biological processes is found at Plainfield, N. J., Essex Falls, N. J., Grand Rapids, Michigan, and in several Oklahoma towns.

Other developments in sewage treatment are sewage filtration on vacuum filters using paper pulp mats at Rockville center, N. Y.; the use of chlorine for concentrating activated sludge by Goudey; Genter's elutriation method for conditioning sludge; and various experiments pointing toward final disposal of sludge by incineration.

E. Hurwitz

DRYING AND DISPOSAL OF SLUDGE AT YORK TOWNSHIP SEWAGE TREATMENT PLANT

By C. Chamberlain

The Canadian Engineer, **67**, 3 (July 17, 1934.) *

Sludge has been dewatered on two (8½ ft. × 8 ft.) FEinc. vacuum filters since 1930. Filter cake amounting to 30 cu. yds. per day is hauled

* The article does not describe the plant or plant structures. It is understood to be an activated sludge plant without any preliminary treatment of the sewage. The sludge that is filtered is excess activated sludge. The plant has an average flow of about 2 M.G.D.

by the Township, spread over land and covered or ploughed in. Three methods of sludge conditioning have been used.

Acid and Lime.—Lime liquor as a by-product from an acetylene plant was mixed with sludge in a trough, and in the proportion of 20 gals. (20 per cent solution) lime liquor to 1,000 gals of sludge. The mixture was thickened and then dosed with sulphuric acid in the mixing trough.

The filter rate was 1½ lbs. per sq. ft. per hr. Cake moisture was 80 per cent. Filter cake when spread was inoffensive, but if piled and covered remained offensive after two years. Digested and activated sludges filtered readily and the process was "fairly easily controlled."

Chemicals cost, per ton of dry solids:

1,540 lbs. Acid @ 1¼c =	$19.25
3 tons Lime Liquor =	3.00
	$22.25

Paper Pulp and Lime.—Paper pulp was obtained by macerating paper in a hammer mill and pulping to convenient consistency. The previously limed sludge was mixed in a trough with the paper pulp, the ratio being 0.88 lb. paper to 1 lb. sludge (dry weight).

The filter rate was 1¼ lbs. per sq. ft. per hr. Cake moisture was 78 per cent. Filter cake became offensive if piled, but was inoffensive when spread. "Almost any kind of sludge could be dewatered" and the process was "easily controlled."

Chemicals cost, per ton of dry solids:

1,700 lbs. Paper @ 9.00c =	$ 7.90
1 ton Lime Liquor	1.00
Power and Labor macerating paper (subject to decrease by improvement of facilities)	5.20
	$14.10

Ferric Chloride.—Excess sludge is pumped continuously to the trough and ferric chloride added from a small solution tank, but without mixing except as results from the pump discharge. Ferric chloride dosage varies from 6 to 12 per cent (dry basis) and averages 9.8. The conditioned sludge (pH 4.8 to 5.8) is passed to the filter in about two minutes.

The filter rate is 2 lbs. per sq. ft. per hr. Cake moisture is 80 per

cent. The filter cake becomes offensive within a short time and must be covered with an equal volume of earth. The process is "not easily controlled."

Chemical cost, per ton of dry solids:

196 lbs. Ferric Chloride @ 2.5c = $4.90

Ferric chloride is purchased in tank cars as 45 per cent solution and is pumped by air pressure to a storage tank. The delivery line is a 2½ inch galvanized pipe which is flushed after use. The chemical is pumped as needed to the small tank which feeds by gravity to the mixing trough.

Filter cake is discharged to a belt conveyor which ascends at 35 deg. and discharges to a bin for storage and delivery to the trucks through a gate. The bin is 5 ft. 9 ins. square and has (apparently) 45 deg. sloping sides.

Abstractor's Note:—In personal communication Mr. Chamberlain ascribes lack of stoppage in the bin to the moisture content of the cake.

FRANK C. TOLLES

LOS ANGELES INCINERATES SEWAGE SCREENINGS

BY H. G. SMITH

Civil Engineering, 4, 293 (June, 1934)

The Los Angeles Hyperion plant screens 130 m.g. sewage daily through bar screens and 1/16-inch slot screens. This removes 3 to 6 per cent of the suspended solids amounting to 33 tons per day—wet.

Screenings were formerly ejected to trenches in the sand dunes and covered. In 1933 an incinerator was built.

Specifications.—General specifications established the requirements of construction and capacity, and asked for proposals which involved guarantees of performance.

Designs were to be based upon burning 50 tons of screenings (wet) in 24 hours, the screenings having 85 per cent moisture, furnishing 8,000 b.t.u. per dry pound and to leave 9 per cent ash. The bidder was to guarantee combustion without sparks, fly ash or offense, and not more than one per cent organic matter in the ash. Smoke was limited to No. 1 Ringelman Scale. The bidder was required to guarantee manhours of labor, and power fuel and water consumption for the screenings as described, and likewise as such might be varied in moisture, ash or B.T.U. content.

Tests.—Fulfillment of guarantees was to be determined by a 72 hour official test at full load. In case of failure, a second test was allowed. Failure to meet guarantees within 30 days was to signify rejection of the plant and its removal. After passing the official test, the plant was to be operated for 90 consecutive days to determine the durability and the requirements of maintenance.

A contract was awarded to the Morse-Boulger Destructor Company. The bid price was $32,500 exclusive of the building, which was erected later by the City. Bid guarantees for operation included Labor at 48 man hours per day.

The Plant.—The plant as built includes a 150 cu. ft. ejector pit for wet screenings, a 24 inch × 8 inch (3 tons per hr.) roll press for dewatering to 70 per cent moisture, a bin of 8 tons capacity for dewatered screenings, a furnace and chimney together with foundations and indicating and recording instruments. The furnace is 27 ft. 9 ins. long, 8 ft. wide and 9 ft. 2 ins. high (outside). It is designed for temperatures of 1300° F. average, 1200° F. minimum, and 1400–1800° normal in the burning chamber. The furnace consists of two refractory burning hearths, one above the other (total 96 sq. ft.). High pressure atomizing oil burners at 20 gals. per hr. are located, one at the upper hearth and one at the end of the lower hearth. The chimney is 3 ft. by 85 ft. and is lined. The flue has an area of 1,298 sq. ins.

Screenings are blown from the screens to the ejector pot which is kept under 15 lb. air pressure. The flow of screenings from the ejector is controlled by a valve connection to the hopper of the continuous roll press. The dewatered screenings are discharged to a weigh pan which dumps automatically when filled and discharges to the storage bin. From the storage bins the screenings are hand raked to one of the four charging openings over the furnace. The screenings ejector and the roll press hopper are equipped with alarms or lights to show whether full or empty. Likewise, there are automatic measurements of the weight of screenings, the amount of expressed water, furnace temperatures and oil, air and current consumption.

Performance Test.—In the official three-day test, the raw screenings showed a moisture content of 83.5 per cent, a B.T.U. value of 9,934, and ash of 10.3 per cent. With corrections because of these variations from the specification figures, the comparison between guarantee and performance was:

	Guarantee	Performance
Capacity, wet tons per day	46.08	53.52
Oil Fuel, gals. per wet ton	9.38	7.09
Air, cu. ft. per wet ton	562.	356.
Power, Kw. per wet ton	0.88	0.28

The pressed screenings averaged 66.2 per cent moisture. The organic content of the ash was less than one per cent. There was no visible smoke or vapor and no odor was noticeable 100 feet from the plant.

The City has housed the installation in a factory type building and has provided an ash ejector and also telephone and electric signals for correlation with the screening plant.

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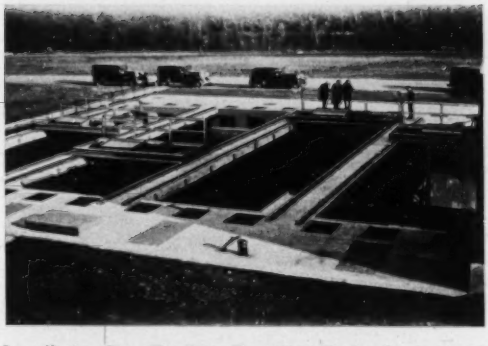

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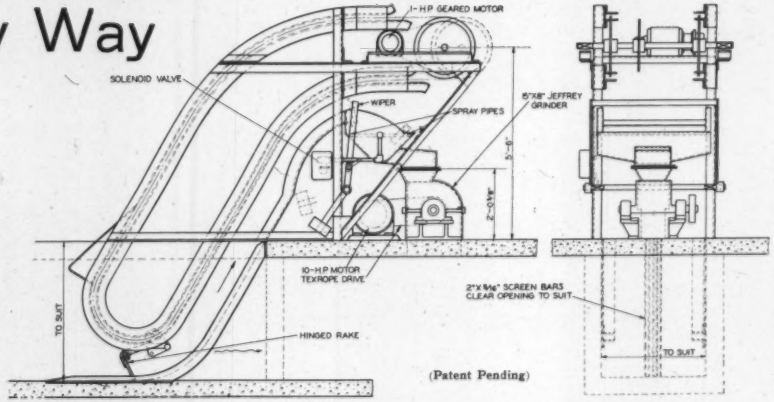

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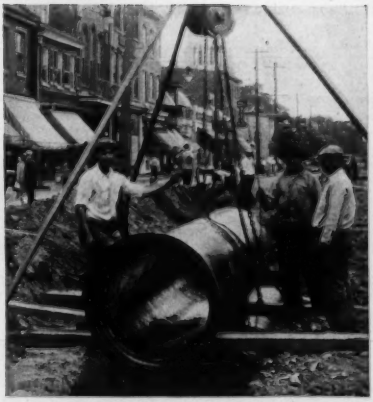

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